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**Pfotenhauer et al.**

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(54) **TORQUE-LIMITING DEVICES, SYSTEMS,  
AND METHODS**

(71) Applicant: **Pro-Dex, Inc.**, Irvine, CA (US)

(72) Inventors: **Alexander M. Pfotenhauer**, Tustin, CA (US); **Manouchehr Goharlaee**, Irvine, CA (US)

(73) Assignee: **Pro-Dex, Inc.**, Irvine, CA (US)

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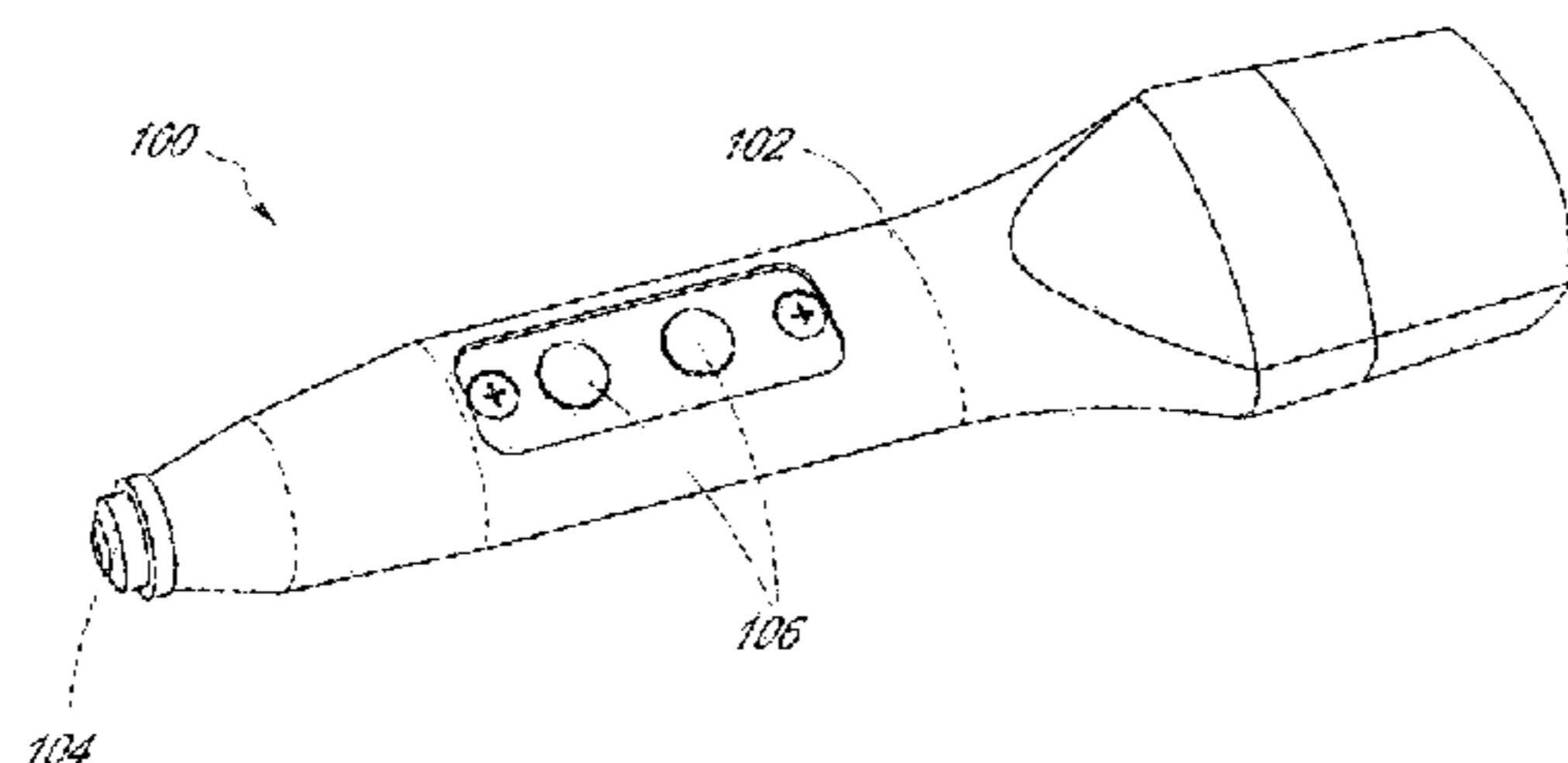
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(52) **U.S. Cl.**  
CPC ..... *A61B 90/03* (2016.02); *A61B 17/1626* (2013.01); *A61B 17/1628* (2013.01); *A61B 2090/031* (2016.02); *A61B 2090/066* (2016.02)

(58) **Field of Classification Search**  
CPC ..... *A61B 90/03*; *A61B 17/1626*; *A61B 2090/031*

See application file for complete search history.



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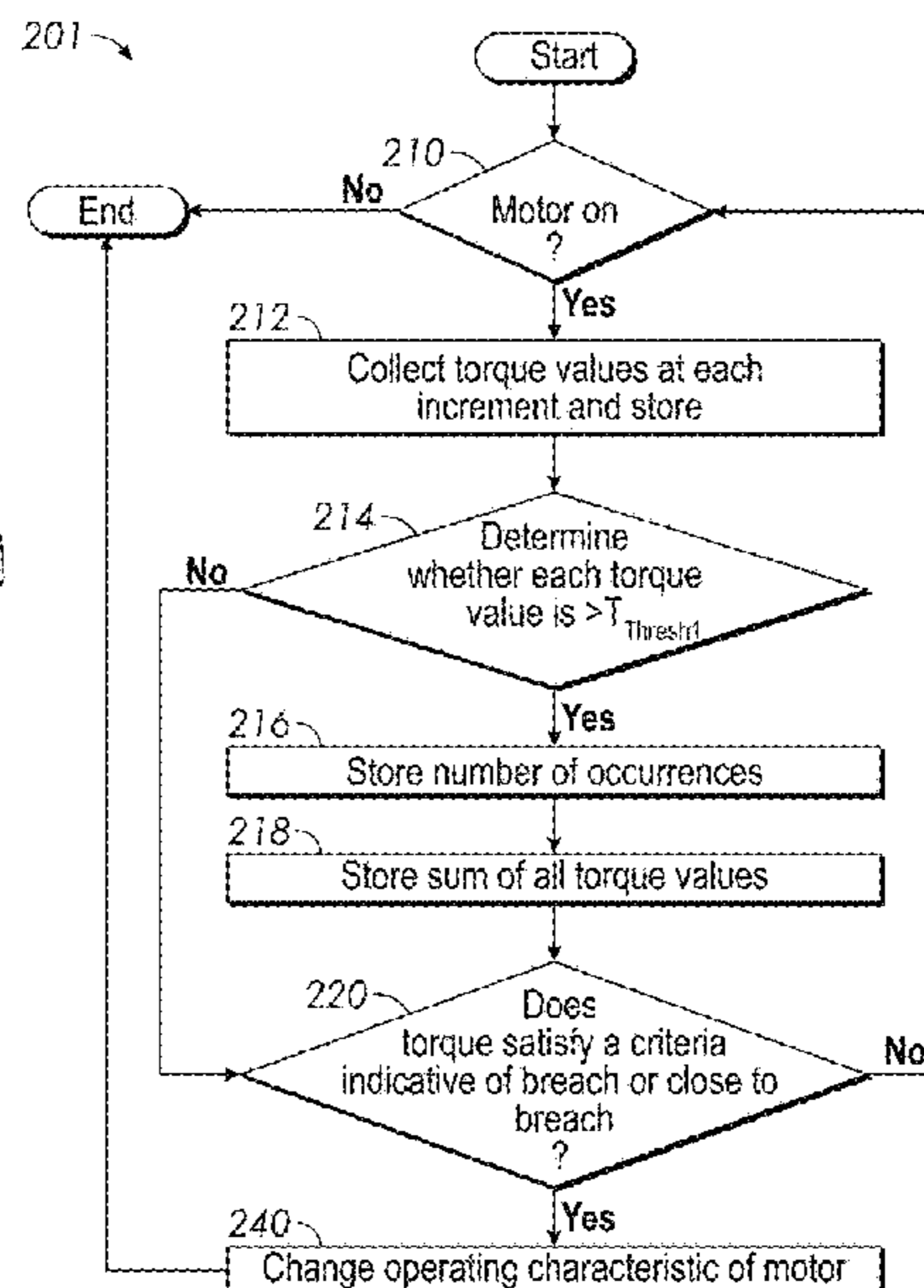
*Primary Examiner* — Christian A Sevilla

(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

Various torque-limiting surgical driver devices, systems, and methods are disclosed. The surgical driver can include a body, a motor that is configured to rotate a drill bit engaged with the surgical driver, and a processor configured to control operation of the surgical driver. The surgical driver can have torque-limiting functionality, such as by monitoring the amount of torque applied to a drill bit and reducing or stopping rotation of the drill bit when certain torque-limiting criteria are met.

**17 Claims, 12 Drawing Sheets**



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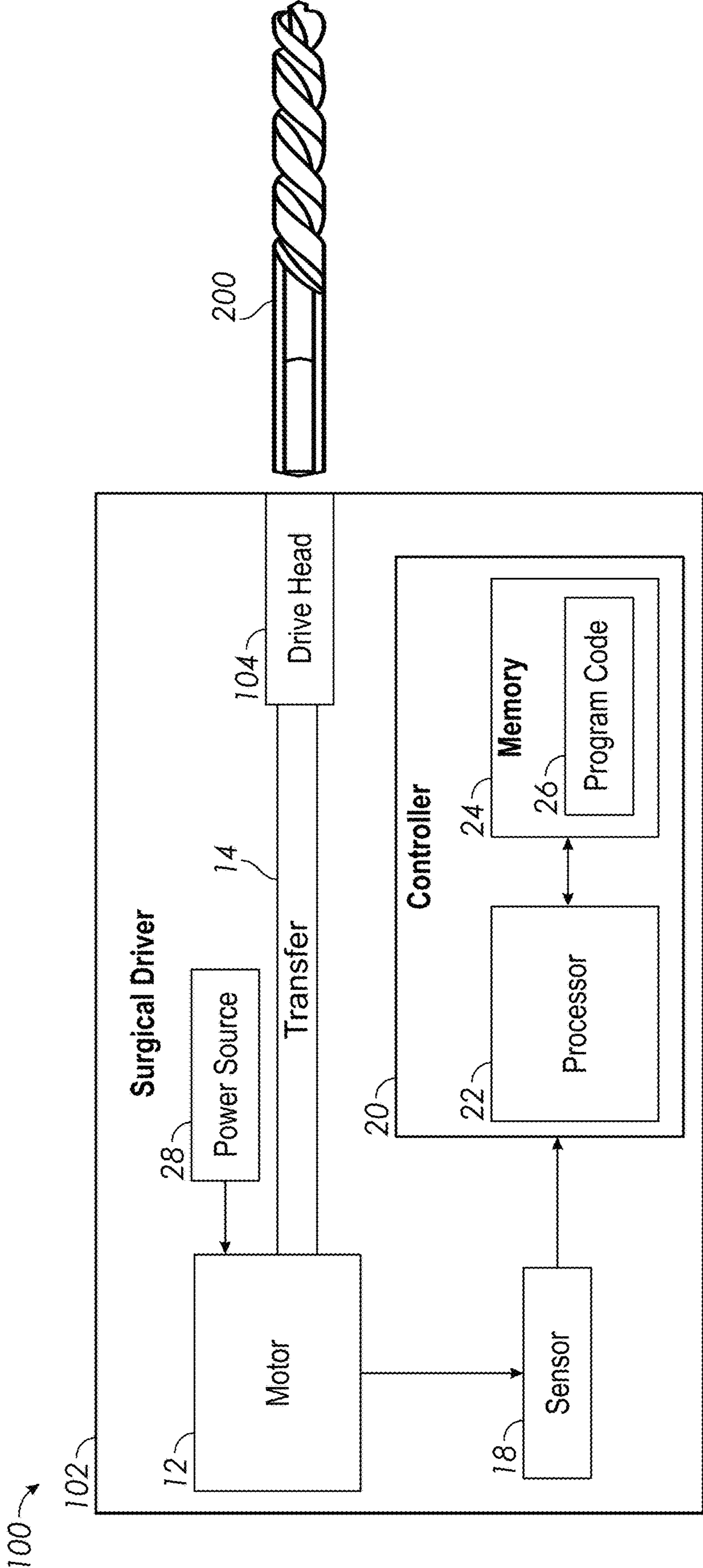


FIG. 1

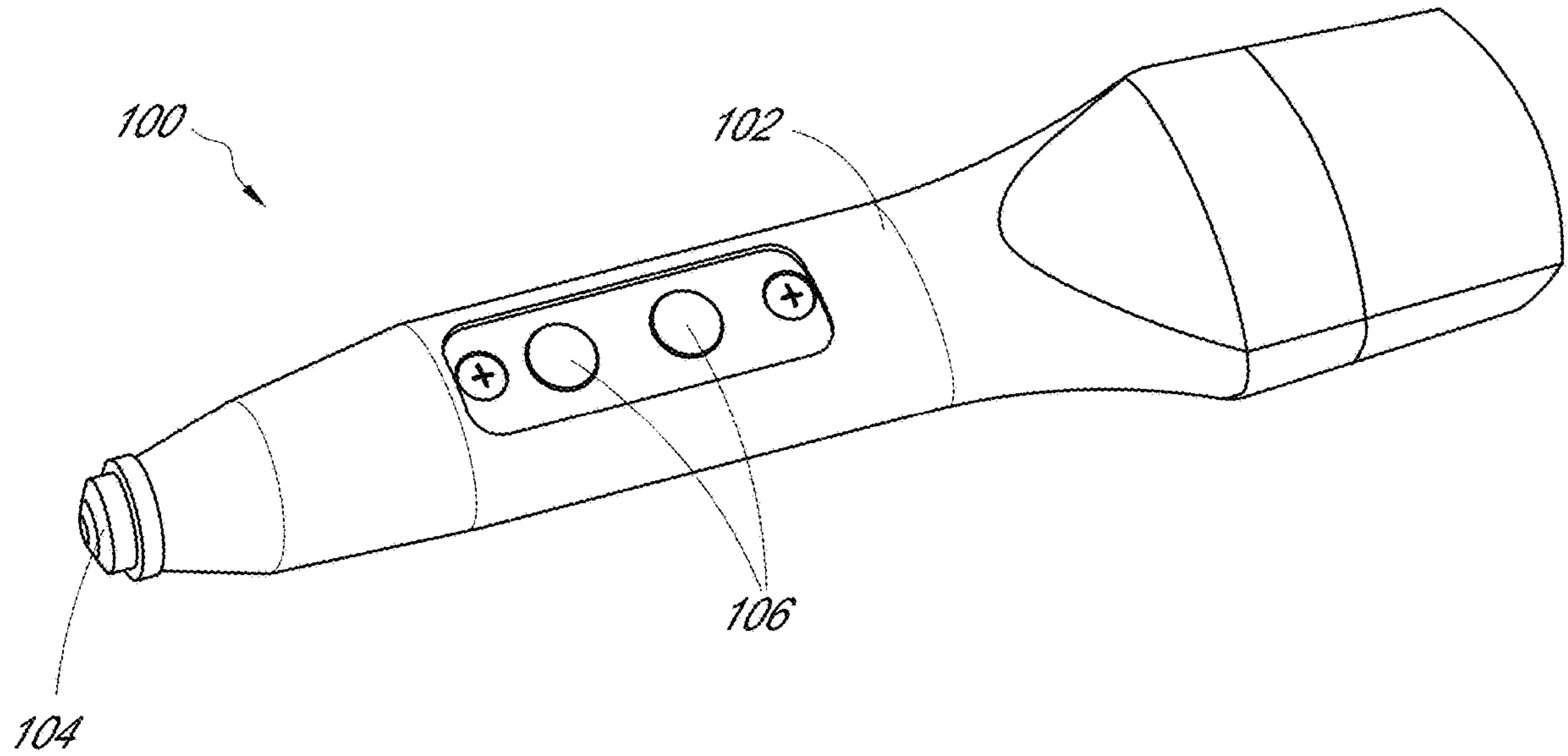


FIG. 2A

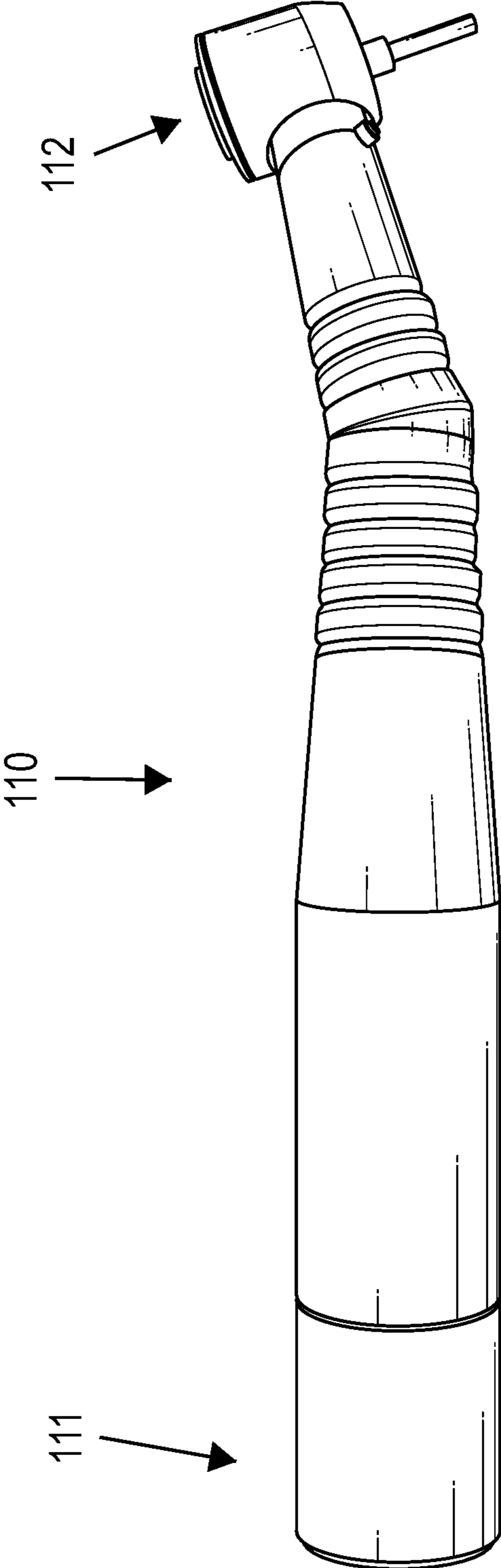


FIG. 2B

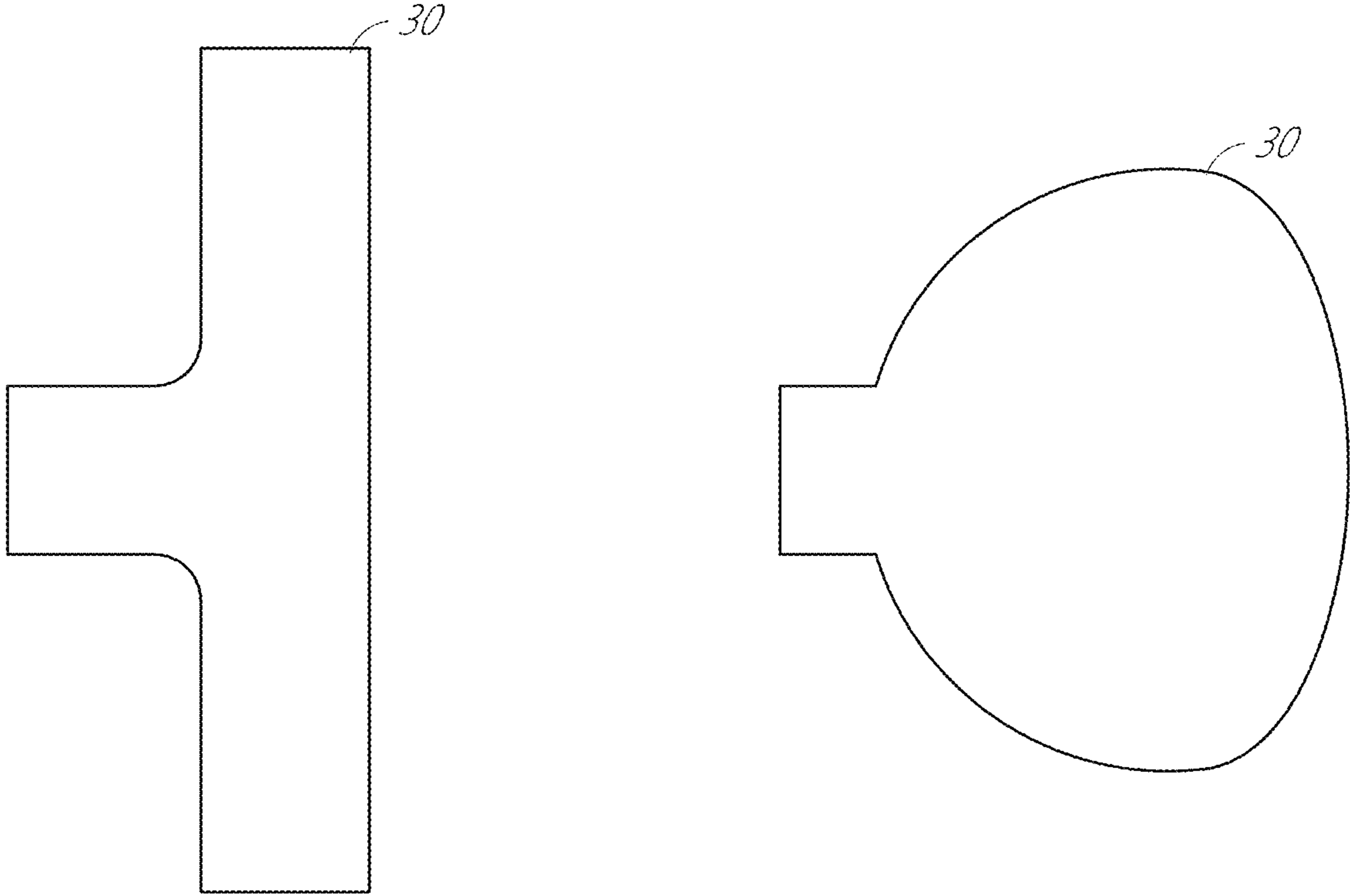
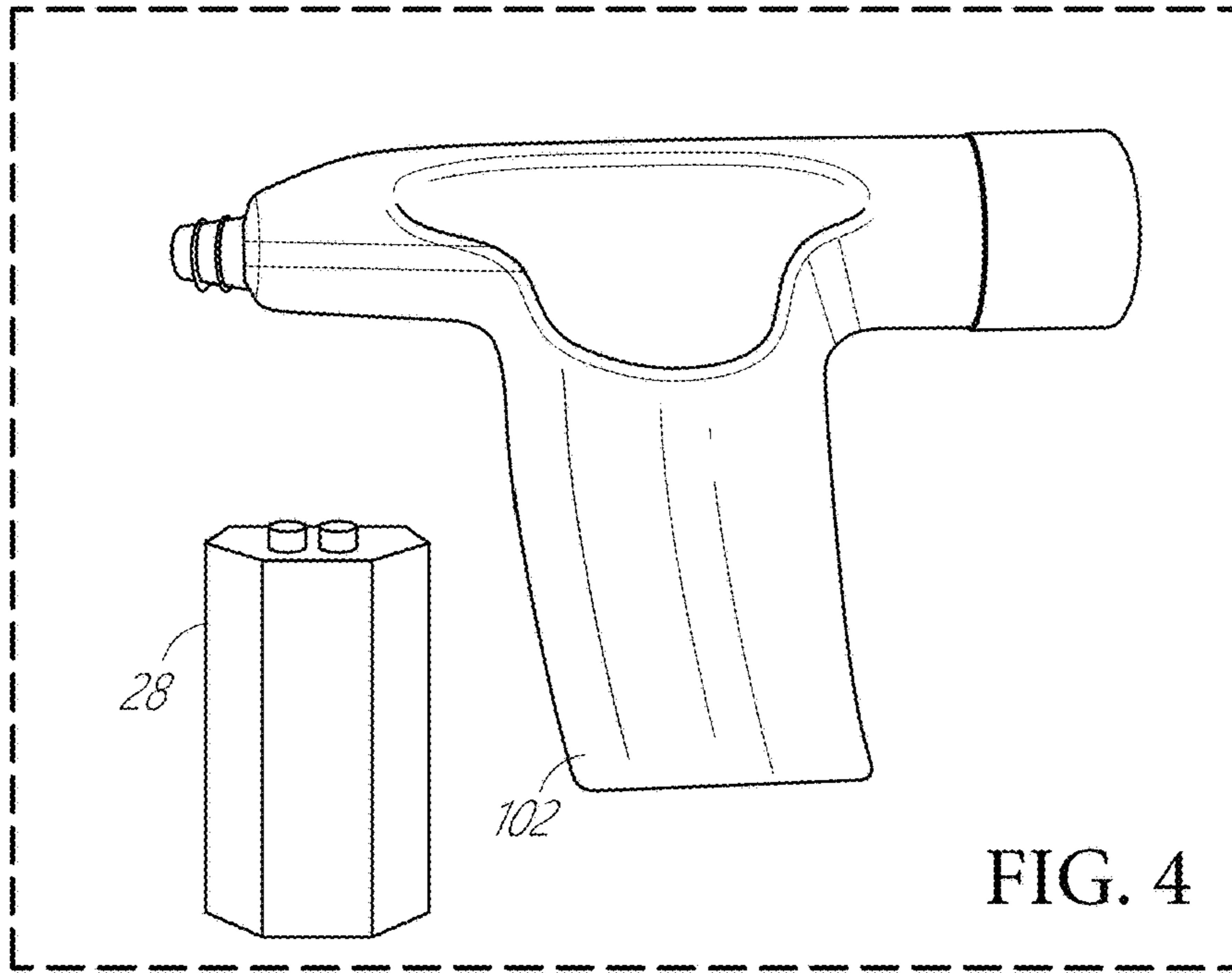


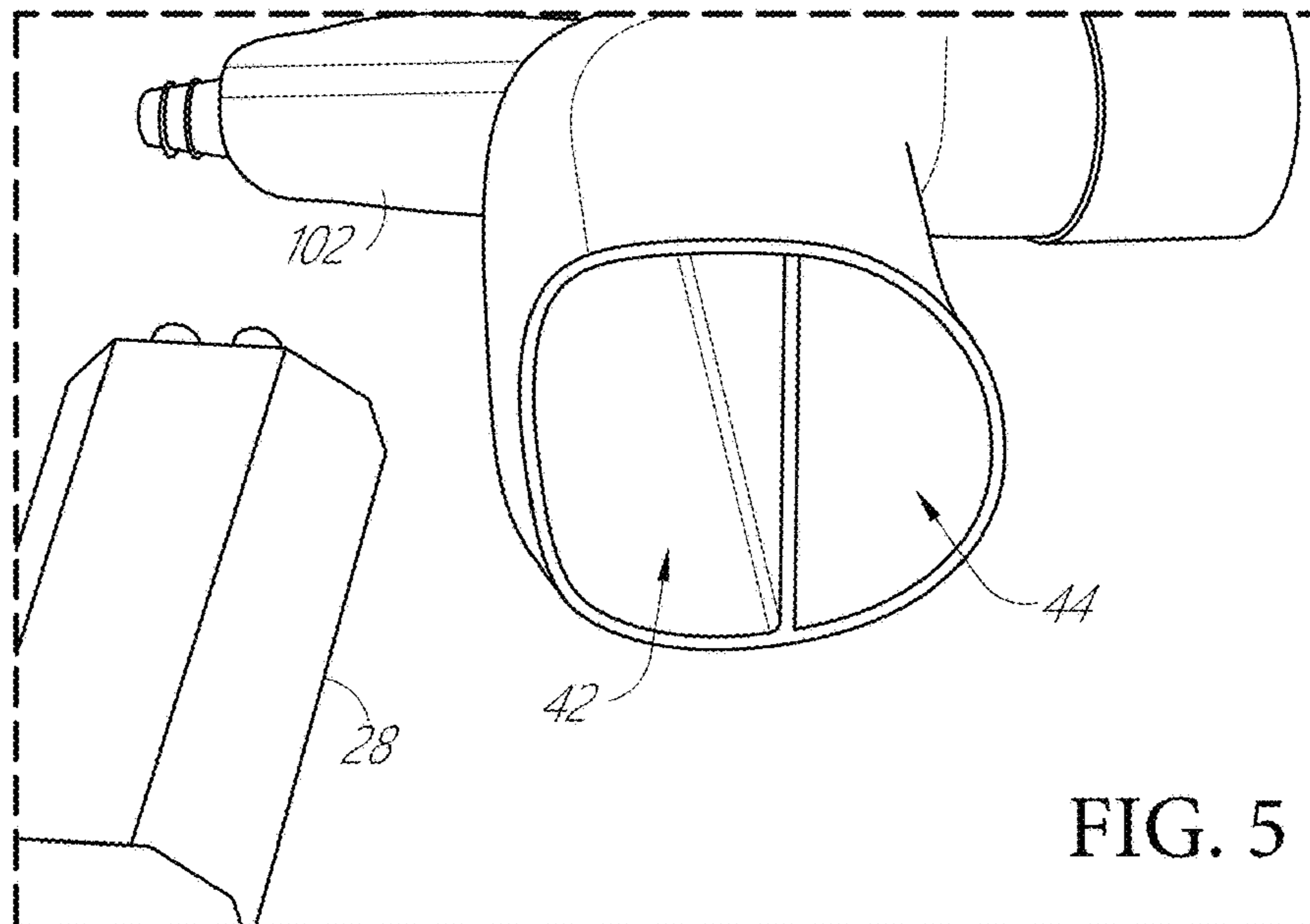
FIG. 3



100



100



100

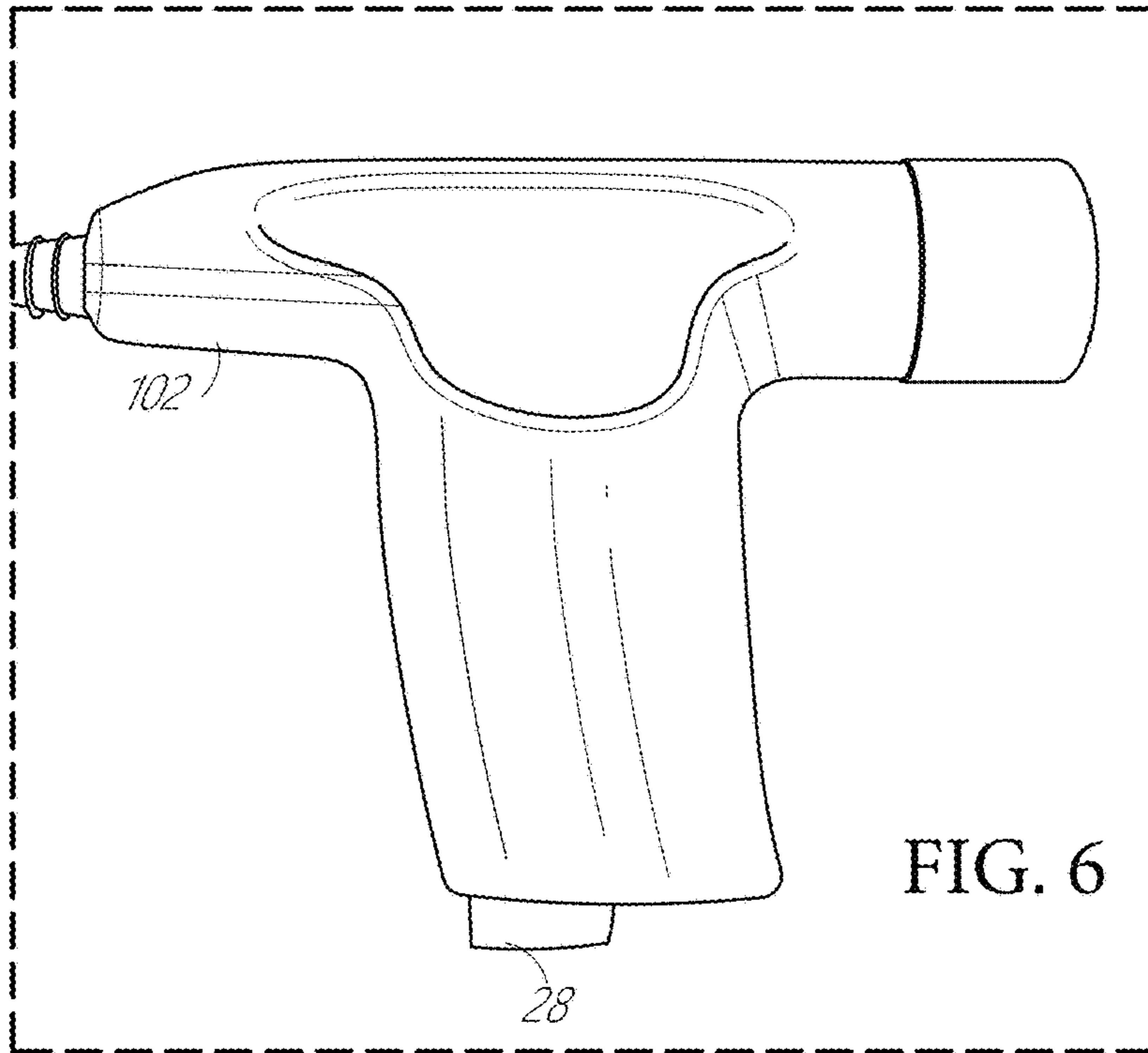


FIG. 6

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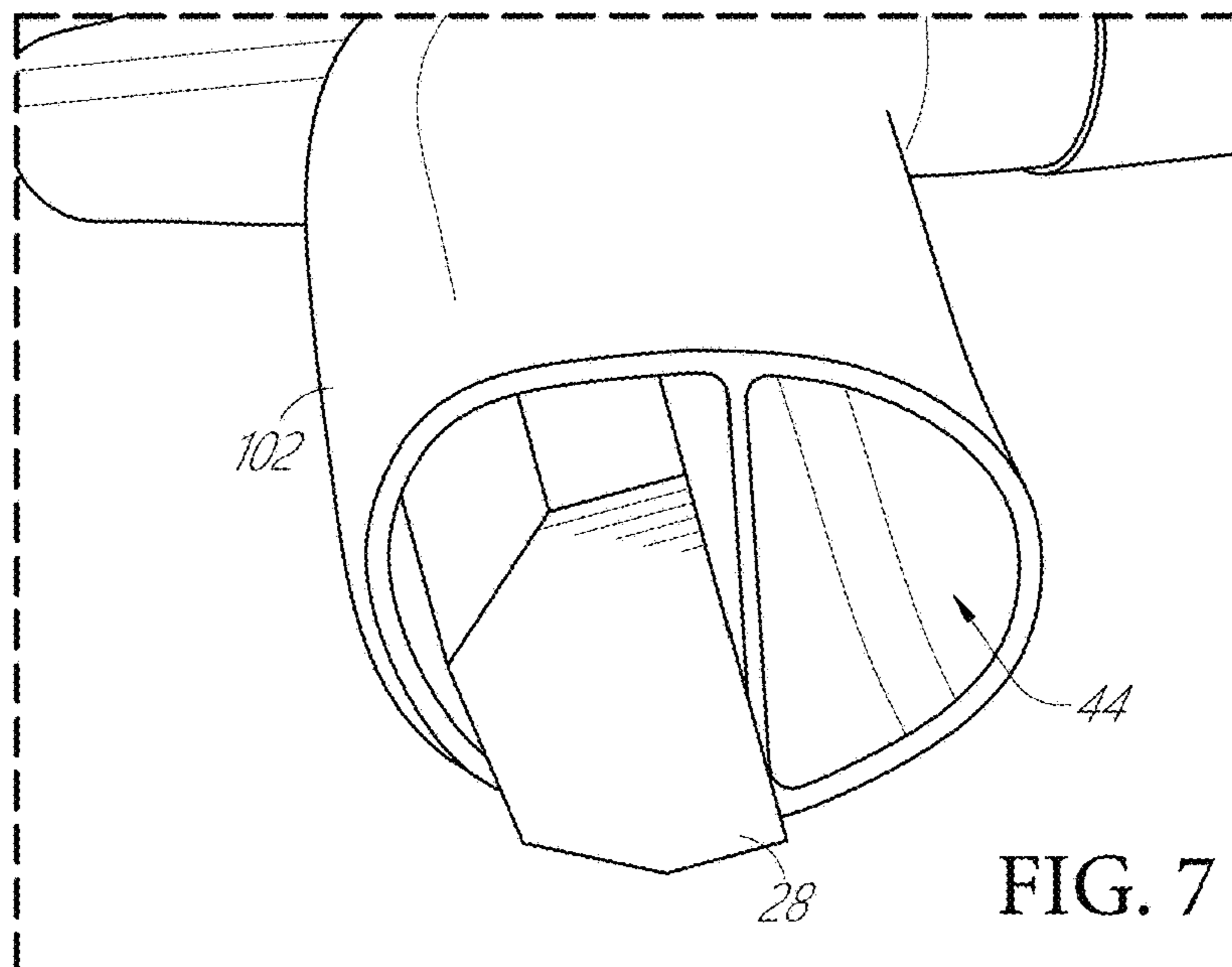


FIG. 7

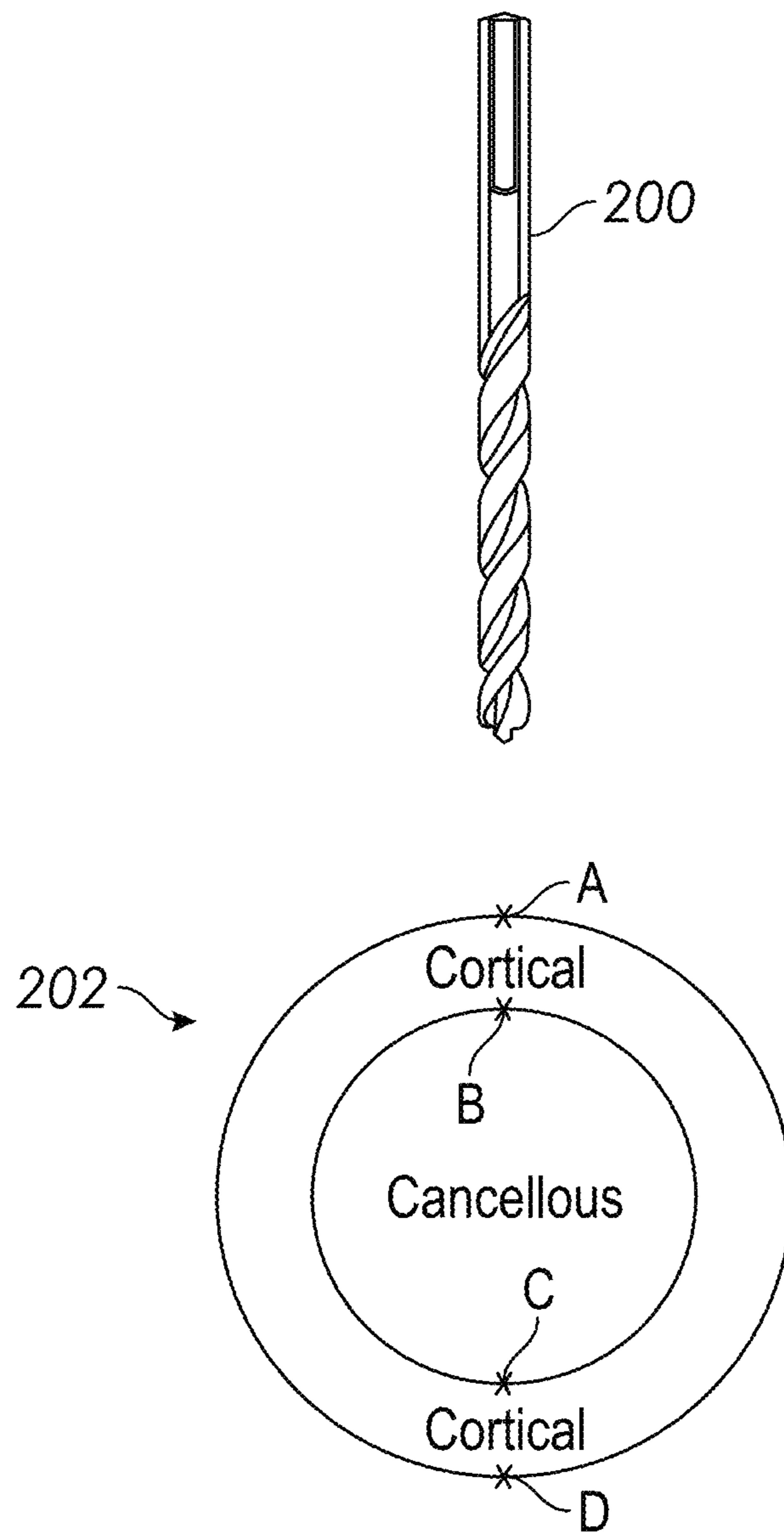


FIG. 8

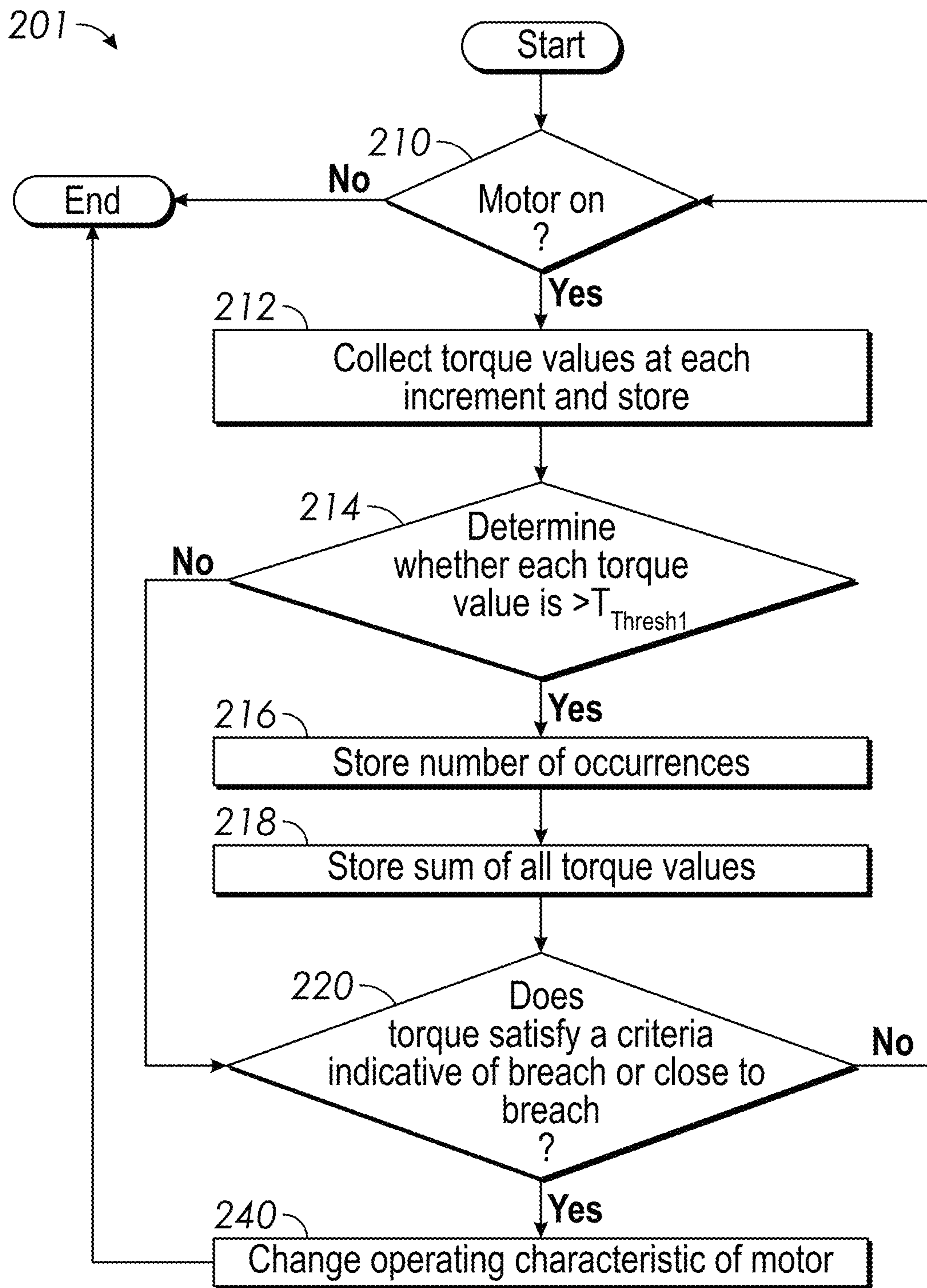


FIG. 9

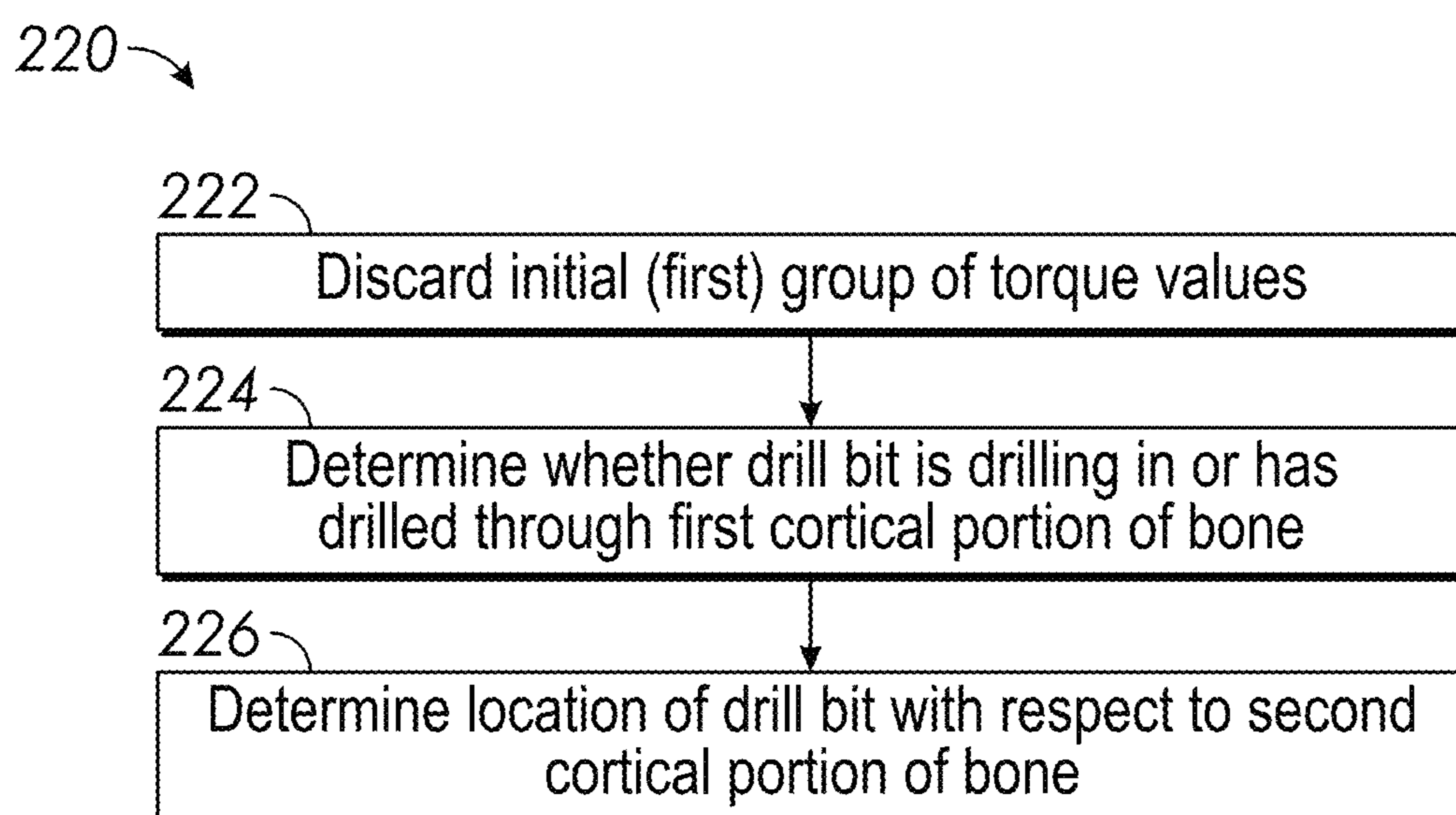


FIG. 10

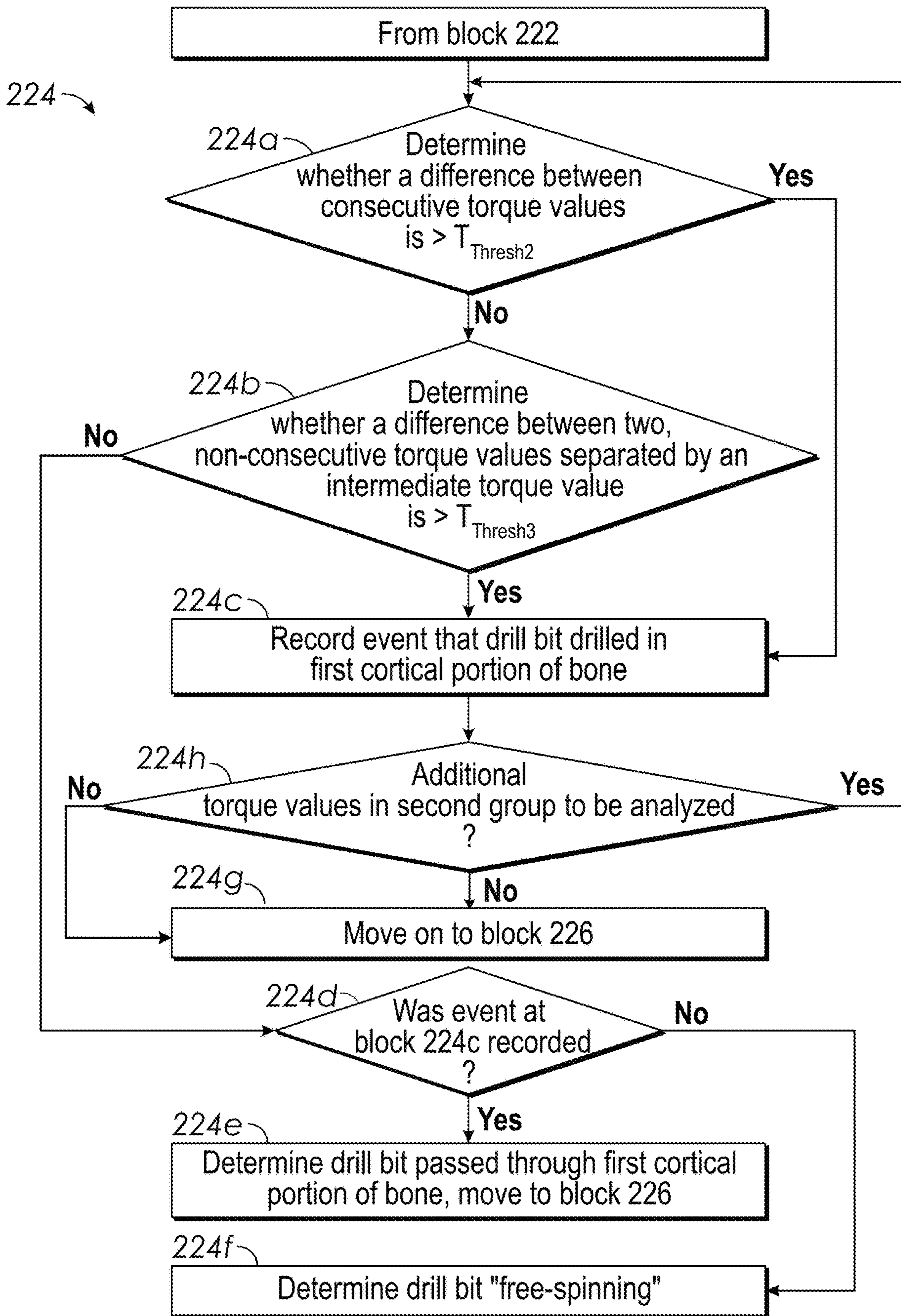


FIG. 11

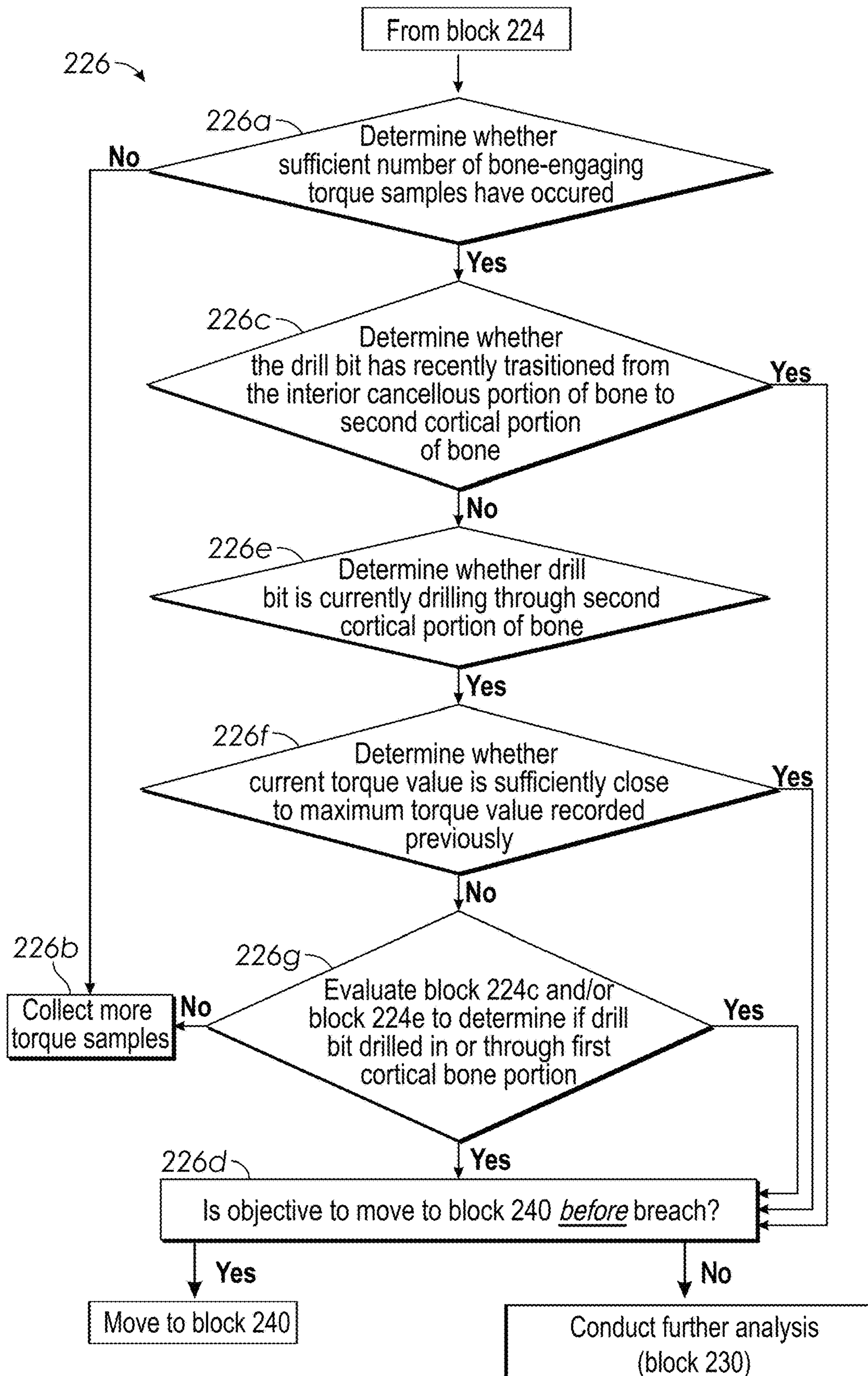


FIG. 12

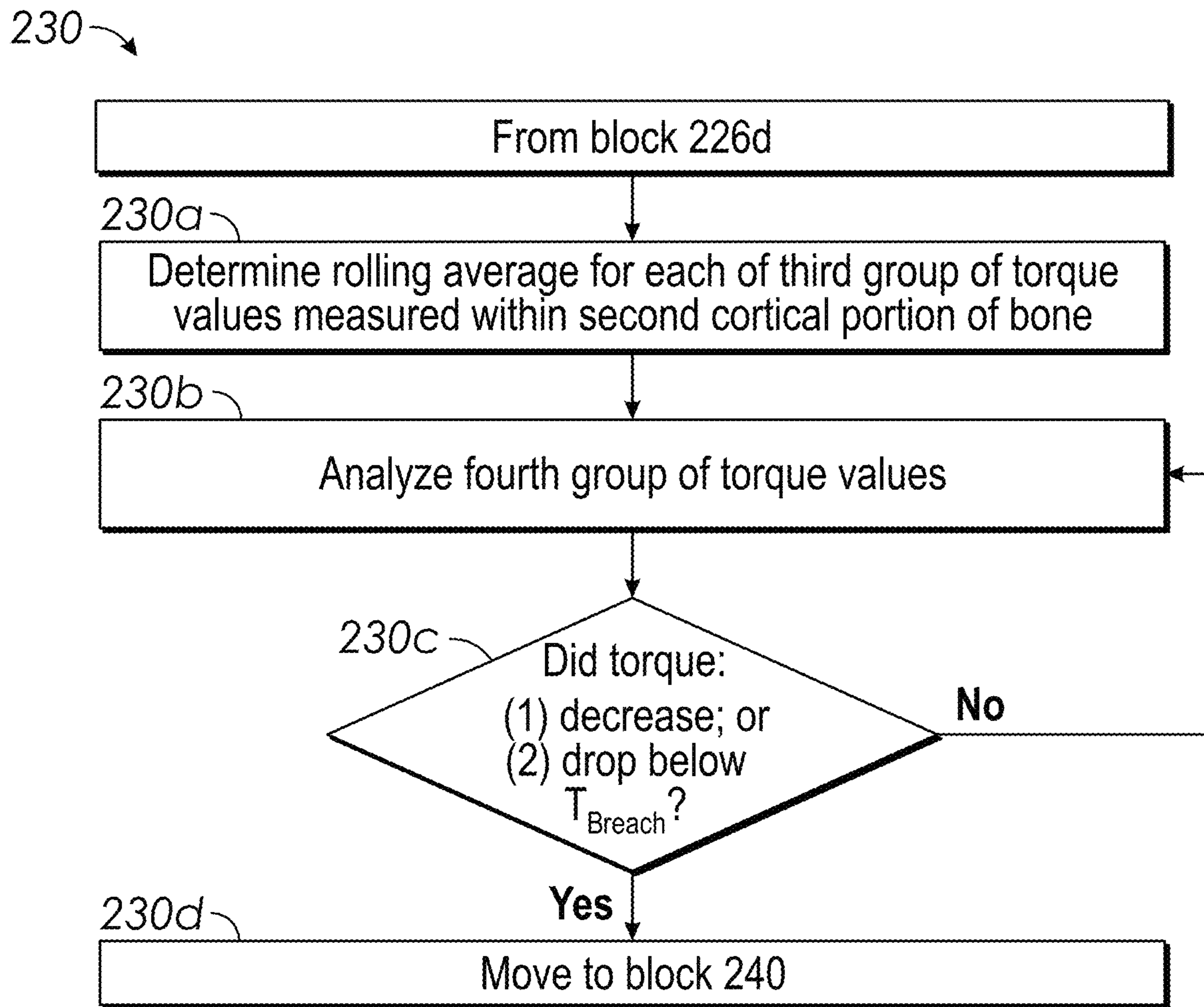


FIG. 13



## TORQUE-LIMITING DEVICES, SYSTEMS, AND METHODS

### CROSS REFERENCE

This application claims from the benefit of U.S. Provisional Application No. 62/719,874, filed Aug. 20, 2018, and titled "TORQUE-LIMITING DRILLING," the entirety of which is incorporated by reference herein.

### BACKGROUND

#### Field

This disclosure generally relates to torque-limiting surgical driver devices, systems, and methods, such as torque-limiting surgical drivers for use in orthopedic surgeries.

#### Certain Related Art

In certain surgical procedures, medical professionals (for example, surgeons) utilize hand-powered instruments to drill into a bone of a patient. As powered surgical instruments have become more commonplace, medical professionals have moved away from manual surgical drilling instruments and methods when drilling and driving into patient bone. Powered surgical instruments operate at much higher speeds than hand-actuated, manual surgical instruments. However, while such powered instruments provide many benefits, it is difficult for medical professionals to determine when a drill bit has transitioned through different layers of the bones and/or when a drill bit has penetrated through the entirety of the bone cross-section.

### SUMMARY OF CERTAIN FEATURES

It can be beneficial to detect when a surgical drill is presently drilling through particular layers of bone, transitions between different layers of the bone, and/or has penetrated through an entirety of a cross-section of bone. Such detection can avoid or reduce potential damage to tissue proximate to a patient's bone, such as tissue or nearby organs. For example, it can be beneficial for a surgical drill to differentiate between varying densities of bone in order to provide continuous feedback as to the current location of a drill bit within the bone. Such "tissue differentiation" or "density differentiation" can help avoid "plunging" of the drill bit through and/or outside the bone which can cause damage to tissue proximate or adjacent the bone. This can be accomplished with a surgical driver that monitors the torque applied to the drill bit and stops or reduces the rotation of the drill bit when certain torque criteria are satisfied. For example, the criteria can include the amount of torque being applied, how the torque is changing over time (e.g., whether the torque is consistently or inconsistently increasing or decreasing), how current torque values compare with previously-measured torque values and/or thresholds. Certain comparisons or thresholds of measured torque values can aid in determining whether present or recent torque values being sensed are indicative of the drill bit being located (or drilling through) a harder portion of the bone, which can in turn indicate that the drill bit is about to exit the bone cross-section. Additionally or alternatively, certain comparisons or thresholds of measured torque values can aid in determining whether present or recent torque values being sensed indicate that the drill bit has breached the bone. As discussed further below, the surgical driver can detect whether the drill

bit is drilling through, or has drilled through, the harder (cortical) portion of the bone around the softer (cancellous) portion of the bone, and/or whether the drill bit has drilled through one or both of the entry and exit portions of the harder (cortical) portion. Some embodiments are configured to detect that the drill bit has passed through a softer tissue and then to stop upon, or soon after, encountering and/or beginning to drill into a harder tissue. For example, to detect that the drill bit has passed through a spinal disk and is at a vertebrae. Certain embodiments operate with algorithms such as those described herein, but without those steps that relate to and/or are dependent on detecting a first cortical layer of bone.

Various surgical drivers and associated systems and methods are disclosed that address one or more of the concerns discussed above, or other concerns. Embodiments of the surgical drivers, systems, and methods can be used for many different procedures, such as reconstructive, clavicle, craniomaxillofacial, thoracic, spinal, fracture repair, and extremity surgical approaches, among others. Further, in the reconstructive process, embodiments can be used for joint replacements (such as for patients suffering from arthritis), reconstructive orthopedics can restore the function of joints by replacing them. This can include knee, hip, and shoulder surgeries, though other surgeries can be used as well. Fracture repair can be used with respect to bones experiencing trauma, such as large bones like the femur. Further, extremities can be reconstructive, which can include joints such as ankles, wrists, hands, fingers, feet, and toes. Each of the determined torque values can vary depending on the particular application, such as those discussed above. Embodiments can be used in the orthopedic realm and outside the orthopedic realm.

Some embodiments are configured to identify differentiations in torque characteristics. In some embodiments, the surgical driver can differentiate different bodily tissue (e.g., different bone tissues) so that the user will know where they are operating (e.g., where the tip of the drill bit is located). In certain embodiments, the surgical driver is configured to reduce or avoid breaching of a bone (e.g., a clavicle), such as with a drill bit.

The surgical driver can include a body and a motor. The motor can be operably connected to a drive head at a distal end of the surgical driver such that the motor can turn the drive head. The drive head can receive a drill bit. The drill bit can be positioned at a desired drill location on a substrate (e.g., a bone) and the motor can be operated to drive the drill bit into a substrate. Various embodiments of the surgical driver can limit and/or control torque applied to the drill bit. Certain embodiments reduce the speed of the drill bit during the drilling process. Various embodiments provide one or more of the advantages described above, or other advantages.

In some embodiments, a powered device (such as a surgical driver) can be capable of determining torque (e.g., by reading current and/or voltage) and a controller (either inside the device or outside the device) can be configured to implement torque-limiting functionality. In some embodiments, the device can be programmed to use current, voltage, and/or torque values to identify the substrate through which the drill bit is drilling and manage drive velocity accordingly. In some embodiments, the device can be programmed to use current, voltage, and/or torque values to identify changes in the drill bit path through more or less dense materials (such as through harder or softer portions of a bone). In some embodiments, the device can identify cortical and cancellous bone using discrete current, voltage,

and/or torque values and can use the values to interpret the current substrate of the drill bit and control the powered device accordingly. For example, some implementations are configured to stop the device if a higher density tissue type is detected, such as a cortical portion of a bone.

Disclosed herein are embodiments of a torque-limiting surgical driver comprising: a body comprising a handle that is configured to be grasped by a user; a motor positioned in the body; a drive head configured to be rotated by the motor and to receive a drill bit; a power source configured to provide electric power to the motor; and a processor positioned in the body. In some embodiments, under the control of the processor, the torque-limiting surgical driver is configured to: apply torque to the drill bit to drill into a bone; monitor current or voltage supplied to the motor; determine, from the current or voltage supplied to the motor, torque values applied to the drill bit as the drill bit drills through the bone; and determine that a torque-limiting condition is satisfied. In some embodiments, the determining that the torque-limiting condition is satisfied comprises: determining that the drill bit has drilled in or through a first cortical layer of the bone; and determining that the drill bit has drilled through a second cortical layer of the bone; and in response to determining that the torque-limiting condition is satisfied, stopping the application of torque to the drill bit.

In some embodiments, the torque-limiting surgical driver is configured to determine whether the drill bit has drilled in or through the first cortical portion of the bone by comparing a difference between a first pair of consecutive torque values to a first threshold. In some embodiments, the torque-limiting surgical driver is configured to determine whether the drill bit has drilled in or through the first cortical portion of the bone by further comparing a difference between a second pair of consecutive torque values to the first threshold. In some embodiments, if the difference between the first pair of consecutive torque values is not greater than or equal to the first threshold, the torque-limiting surgical driver is further configured to compare a difference between a first pair of non-consecutive torque values with a second threshold, wherein the second threshold is greater than the first threshold. In some embodiments, if the difference between the first pair of non-consecutive torque values is not greater than or equal to the second threshold, the torque-limiting surgical driver is further configured to compare a second pair of non-consecutive torque values with the second threshold.

In some embodiments, the torque-limiting surgical driver is further configured to determine at least one of: whether the drill bit has drilled through an entry point of the second cortical portion of the bone; and whether the drill bit is drilling in the second cortical portion of the bone. In some embodiments, the torque-limiting surgical driver is configured to determine whether the drill bit has drilled through the entry point of the second cortical portion of the bone by comparing a difference between a second pair of consecutive torque values to a second threshold, the second pair of consecutive torque values obtained after the first pair of consecutive torque values. In some embodiments, the second threshold is equal to a percentage of an average of a subset of all the determined torque values. In some embodiments, the subset of all of the determined torque values is equal to all of the determined torque values that are greater than or equal to a third threshold, wherein the third threshold is indicative of drilling through a material other than air. In some embodiments, the torque-limiting surgical driver is configured to determine whether the drill bit is drilling in the second cortical portion of the bone by comparing a differ-

ence between a current torque value and a maximum measured torque value to a second threshold.

In some embodiments, in response to a determination that the drill bit has drilled through the entry point of the second cortical portion of the bone or a determination that the drill bit is drilling in the second cortical portion of the bone, the torque-limiting surgical driver is further configured to determine an average torque value, the average torque value representative of the torque values measured when the drill bit is drilling in the second cortical portion of the bone. In some embodiments, the torque-limiting surgical driver is further configured to determine a difference between a first torque value and the average torque value, the first torque value being a current torque value measured by the torque-limiting surgical driver.

In some embodiments, the surgical driver is configured to limit the amount of torque applied to the drill bit in response to a determination that the first torque value is less than the average torque value. In some embodiments, the torque-limiting surgical driver is further configured to: determine a difference between a second torque value and the average torque value, the second torque value measured prior to the first torque value; and limit the amount of torque applied to the drill bit in response to a determination that both of the first and second torque values are less than the average torque value.

Disclosed herein are methods of controlling a torque-limiting driver to limit the amount of torque applied to a drill bit after breaching a bone. In some embodiments, the torque-limiting driver comprises a body with a handle, a motor positioned in the body, a drive head that is configured to receive a drill bit and to be rotated by the motor so as to enable the drill bit to drill into the bone, and a processor. In some embodiments, under the control of the processor the method comprises: driving the drill bit into the bone, wherein the bone comprises a first cortical layer, a second cortical layer, and a cancellous layer in between the first and second cortical layers; detecting torque values when the drill bit is drilling into the bone; determining whether the drill bit has drilled in the first cortical layer of the bone; determining whether the drill bit has drilled through and exited the second cortical layer of the bone; and in response to determining that the drill bit has drilled through and exited the second cortical layer of the bone, stopping the driving of the drill bit. In some embodiments, the step of determining whether the drill bit has drilled in the first cortical layer of the bone comprises comparing a difference between a first pair of consecutive torque values to a first threshold. In some embodiments, the method further comprises determining at least one of: whether the drill bit has drilled through an entry point of the second cortical layer of the bone; and whether the drill bit is drilling in the second cortical layer of the bone.

In some embodiments, in response to a determination that the drill bit has drilled through the entry point of the second cortical layer of the bone or a determination that the drill bit is drilling in the second cortical layer of the bone, the method further comprises determining an average torque value, the average torque value representative of torque values measured when the drill bit is drilling in the second cortical layer of the bone. In some embodiments, the method further comprises determining a difference between a first torque value and the average torque value, the first torque value being a current torque value measured by the torque-limiting surgical driver. In some embodiments, the method further comprises limiting the amount of torque applied to the drill bit in response to a determination that the first torque value is less than the average torque value.

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Any of the structures, materials, steps, or other features disclosed above, or disclosed elsewhere herein, can be used in any of the embodiments in this disclosure. Any structure, material, step, or other feature of any embodiment can be combined with any structure, material, step, or other feature of any other embodiment to form further embodiments, which are part of this disclosure.

The preceding summary is meant to be a high-level summary of certain features within the scope of this disclosure. The summary, the following detailed description, and the associated drawings do not limit or define the scope of protection. The scope of protection is defined by the claims. No feature is critical or indispensable.

## BRIEF DESCRIPTION OF THE DRAWINGS

Certain features of this disclosure are described below with reference to the drawings. The illustrated embodiments are intended to illustrate, but not to limit the embodiments. Various features of the different disclosed embodiments can be combined to form further embodiments, which are part of this disclosure.

FIG. 1 schematically illustrates an example embodiment of a surgical driver.

FIG. 2A illustrates a perspective view of the surgical driver of FIG. 1.

FIG. 2B illustrates an attachment that can be used with the surgical driver of FIG. 1.

FIG. 3 illustrates example end views of handle shapes for embodiments of a surgical driver.

FIGS. 4-7 illustrate examples of a surgical driver comprising a body with a handle that includes a power source, such as a battery.

FIG. 8 schematically illustrates a drill bit and a cross-section of a bone in accordance with aspects of this disclosure.

FIG. 9 illustrates an example method for torque-limiting drilling in accordance with aspects of this disclosure.

FIG. 10 illustrates a method of conducting a drill bit location analysis with can be used in the method of FIG. 9.

FIG. 11 illustrates a portion of the method of FIG. 10 in more detail.

FIG. 12 illustrates a portion of the method of FIG. 10 in more detail.

FIG. 13 illustrates additional features of the method of FIG. 10.

## DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

Various features and advantages of the disclosed technology will become more fully apparent from the following description of the several specific embodiments illustrated in the figures. These embodiments are intended to illustrate the principles of this disclosure. However, this disclosure should not be limited to only the illustrated embodiments. The features of the illustrated embodiments can be modified, combined, removed, and/or substituted as will be apparent to those of ordinary skill in the art upon consideration of the principles disclosed herein.

## Overview of the Surgical Driver

Various embodiments of torque-limiting devices, systems, and methods are disclosed. For purposes of presentation, the devices are called “surgical drivers.” A surgical driver can be any powered device capable of drilling a drill bit into, for example, a bone of a patient. Several embodiments are configured to drive drill bits into a bone. However, the

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features, characteristics, and/or operation of the surgical drivers described herein can be applicable in other contexts. For example, the features, characteristics, and/or operation of the surgical drivers described herein can be applicable to drive screws into a bone. Additionally, while the phrase “surgical driver” is used herein, such phrase does not limit this disclosure only to “surgical” contexts. Rather, the devices, methods, systems, features, characteristics, and/or operations discussed herein can be applicable to other contexts as well.

As more fully described below, the devices, systems, and methods can determine when to stop a drill bit being driven into various types and/or layers of bone so as to avoid “plunging” through the bone and potentially damaging nearby tissue. The term “plunging” refers to when a drill bit transitions from a state where it is drilling through bone to a state where it breaches the bone and advances away from the bone and into and/or through nearby tissue proximate to the bone.

Certain embodiments of the disclosed surgical drivers can be used, for example, as a powered surgical device in an on-plane form factor, a powered surgical device in an on-plane form factor for clavicle applications, a powered surgical device in an on-plane form factor for spinal applications, a powered surgical device in an on-plane form factor for extremities, and/or a powered surgical device in an on-plane form factor for large bone. The surgical drivers can be used for other procedures as well, and the particular procedure is not limiting. In some embodiments, the surgical driver can be operated remotely, for example, through the use of robotics.

As shown in FIG. 1, a torque-limiting surgical driver 100 can include a body 102 (also called a “housing,” “handle,” or “casing”) that supports a motor 12. A transfer assembly 14 (e.g., one or more shafts, gears, etc.) operably connects the motor 12 to a drive head 104 at a distal end of the surgical driver 100 such that the motor 12 can turn the drive head 104. The drive head 104 can receive a drill bit 200 (also referred to herein as “bit”) capable of drilling through portions of bone of a patient. Thus, the drill bit 200 can be positioned at a desired location on a substrate (e.g., a bone) and the motor 12 can be operated to drive the drill bit 200 into the substrate. In some applications, the motor 12 can be operated to rotate the drive head 104 to drive the drill bit 200 into and/or through portions of a bone, such as a clavicle bone. In some embodiments, the head 104 can receive a bit that engages with and drives a surgical screw of other fastener.

In some variants, the motor 12 is powered by a power source, such as a source of AC or DC electrical power. In some embodiments, the motor 12 is powered by an on-board power source 28, such as a battery, capacitor, or otherwise. In some embodiments, the motor 12 is configured to receive power from an external source, such as from a console, wall socket, or other external power source. In some embodiments, the motor 12 is a brushless DC motor. In some embodiments, the motor 12 is a three-phase electric motor. The motor 12 can include one or more hall sensors, which can send signals to the controller 20 to enable the controller 20 to determine the number of revolutions of the motor 12. In certain variants, the controller 20 determines the number of revolutions of the bit 200 from the number of revolutions of the motor 12.

The surgical driver 100 can monitor and/or limit the torque that the surgical driver 100 is applying to the drill bit 200 during the drilling process. For example, as described in more detail below, the surgical driver 100 can include a

sensor **18** that senses the current supplied to the motor **12**. The sensor **18** can send such data to a controller **20**, which can include a processor **22** coupled with a memory **24**, along with other electronic components. Because, in some implementations, the current supplied to the motor **12** can be proportional to the torque applied to the drill bit **200**, the controller **20** can dynamically determine the amount of torque being applied to the drill bit **200**. In certain variants, the controller **20** is configured to determine or receive signals indicative of one or more of the following data features: current supplied to the motor **12**, number of revolutions of the drill bit **200** and/or motor **12**, speed of the motor **12**, or otherwise.

As described in more detail below, various embodiments of the surgical driver **100** can include one or more algorithms adapted to limit and/or control the torque applied to a drill bit **200**. The algorithms can be included in the memory **24** as program code **26** to be implemented on a computer-readable non-transitory medium. The processor **22** can execute the program code **26** to perform various operations, such as determining a torque limit, instructing the motor **12** to cease operation, instructing a power source **28** to reduce and/or stop providing power to the motor **12**, or other operations. The processor **22** and/or program code **26** can control and/or implement any of the features described in this disclosure, such as any of the torque-limiting features. Some implementations are configured to stop the rotation of the drill bit **200** by shutting-off (e.g., substantially or totally) the power to the motor **12**. Certain implementations include a brake to actively decelerate the motor **12** or components. For example, some implementations include a friction or electromagnetic brake.

In various embodiments, the surgical driver **100** can include one or more computers or computing devices that implement the various functions described herein under the control of program modules stored on one or more non-transitory computer storage devices (e.g., hard disk drives, solid state memory devices, etc.). Each such computer or computing device typically includes a hardware processor and a memory. Where the surgical driver **100** includes multiple computing devices, these devices may, but need not, be co-located. In some cases the surgical driver **100** may be controlled by cloud-based or shared computing resources, which can be allocated dynamically. The processes and algorithms described herein may be implemented partially or wholly in application-specific circuitry, such as Application Specific Integrated Circuits and Programmable Gate Array devices. The results of the disclosed processes and process steps may be stored, persistently or otherwise, in any type of non-transitory computer storage such as, e.g., volatile or non-volatile storage.

FIG. 2A further illustrates an example of a surgical driver **100**. As shown, the body **102** of the surgical driver **100** can include an input device **106**, such as buttons, switches, or otherwise. Through the input device **106**, a user can control aspects of the operation of the surgical driver **100**, such as the controller **20**. For example, the user can instruct the surgical driver **100** regarding rotational direction (e.g., forward or reverse), speed, and/or otherwise. The input device **106** may power the surgical driver **100** on or off, or maintain the surgical driver **100** in standby mode. In some embodiments, the surgical driver **100** may have variable speed options as well as forward and reverse capabilities.

In some embodiments, different attachments can be removably attached to the surgical driver **100**, such as at a collet of the surgical driver **100**. An example of an attachment **110** is shown in FIG. 2B. The attachment **110** can allow

a user to access harder to reach areas, e.g., as shown, the attachment can include an offset of about: 40°, 50°, 60°, 70°, 80°, 90°, 100°, 110°, 120°, or other values. The attachment **110** can change the rotational plane of the surgical driver **100**. Further, the attachment **110** may be an extension for further reaching positions. The attachment **110** can be selectively connected to and/or removed from the surgical driver **100**, such as by connecting or disconnecting from a collet of the surgical driver **100**. As illustrated, the attachment **110** can comprise a low-profile and/or elongate configuration and can extend the reach of activity. This can be beneficial in certain types of procedures, such as certain thoracic procedures involving a posterior approach to access anterior ribs. In some embodiments, the attachment **110** comprises an extension adaptor with a first end **111** and a second end **112**. The first end **111** can be configured to mate with the drive head **104** of the surgical driver **100**. The second end **112** can include a drill bit and/or can be configured to mate with a drill bit and/or can be configured to mate with a screw. The attachment **110** can include a power transmission assembly (e.g. a drive shaft) that operably connects the drive head **104** of the surgical driver **100** to the second end **112** of the attachment **110**. For example, the power transmission assembly can convey rotational motion from the drive head **104** to the second end **112** of the attachment **110**. In various embodiments, the attachment **110** is configured to enable drilling into a target site (e.g., a bone) that is spaced a substantial distance apart from the body **102** of the surgical driver **100** (e.g., at least about: 10 mm, 25 mm, 50 mm, 75 mm, 100 mm, 150 mm, 200 mm, 250 mm, 300 mm, distances between the aforementioned distances, or other distances). In some embodiments, the attachment **110** has a reflective and/or mirror-like surface, which can be added, attached, or integrated into the attachment **110** to enhance visibility of the target site. The attachment **110** can be articulating or fixed with respect to the body **102** of the surgical driver **100**. The attachment **110** can be configured for use with the surgical driver **100**, which can include torque-limiting functionality. In some embodiments, the attachment **110** is configured for use with a driver device that does not include torque-limiting functionality.

In some embodiments, the surgical driver **100** can include a mode switch (or similar mechanism) that can allow the user to toggle between modes, such as the powered and manual modes discussed below. In some embodiments, the mode switch can change the parameters of the surgical driver **100** based on a specific type of drill bit. In some embodiments, the mode switch can allow the surgical driver **100** to recognize the presence of different adapters or attachments.

In some embodiments, the body **102** may provide a user with visual output on certain parameters of the surgical driver **100**, such as, power status, mode, speed, or otherwise. Some embodiments are configured to provide trajectory orientation, such as through the use of MIMS (Medical Information Management System), MEMS (Micro-Electromechanical Systems), gyroscopic, or other technology that can cue a user about the orientation of the surgical driver. In some embodiments, the surgical driver **100** is configured to indicate (e.g., to a user) deviations from a “zeroed” orientation, such as the angular deviation from a horizontal or vertical position. In some embodiments, the body **102** can include an LED or LCD display to provide information, to the user. In some embodiments, the surgical driver **100** can connect to an outside display, such as a monitor, such as through a wireless network, to provide a visual output to the outside display. In some embodiments, haptic cues (e.g.,

small vibrations) can provide information to the user. In some embodiments, electromagnetic field (EMF) or Hall Effect sensors can be incorporated into embodiments of the surgical driver **100**.

Various shapes of the surgical driver **100** are contemplated. For example, some embodiments are on plane, which can enhance feel. In this disclosure, the term “on plane” describes a device with a generally linear arrangement. This is in contrast to “off plane” devices, which generally have an L-shaped arrangement, such as a pistol grip. In some embodiments, the surgical driver **100** has an on plane configuration in which the tip is generally in line with the user’s hand, such as the tip and the handle being generally collinear. In some variants, the surgical driver **100** has an off plane configuration, such as having a pistol grip.

An on plane configuration can have a number of advantages. For example, an on plane configuration can allow a user to apply force through the surgical driver to the screw along a linear axis, rather than, for example, through a curve or elbow. In some implementations, an on plane design reduces or eliminates a moment of force that can be associated with certain pistol grip designs, such as due to force being applied to the handle of the pistol grip device and then being transferred through the barrel of the pistol grip device. Reducing or eliminating the moment can increase control of the screw and/or decrease user fatigue (e.g., by reducing exertion needed to counteract the moment). Some embodiments with an on plane configuration can avoid or reduce slippage of the drill bit **200** relative to the substrate, or at least increase the chance that such slippage will occur generally in a desired direction. For example, the on plane arrangement can locate the fingers closer to the drill bit than a pistol grip design, which can enable the user to better detect when slippage is occurring, or is about to occur, and to take action in response.

In some embodiments, an on plane configuration allows a user to use larger muscles (e.g., muscles of the upper arm) compared to pistol grip devices (e.g., which may require usage of wrist muscles or other smaller muscles). The engagement of the larger muscles can provide greater strength and/or control. In some embodiments, there may be no cantilever or no pistol grip.

The on plane arrangement can provide an improved weight distribution, such as by removing weight from a cantilever from the handle. In some arrangements, an on plane configuration can enhance the sensitivity with which a user can discern characteristics of the drill bit and/or the substrate. For example, while large muscles can control the initial driving, the fingers, located closer to the tip than if an off plane arrangement, can be used for final manipulations. Thus, the user can use their fingers for fine-tuning, which can provide more dexterity when handling the surgical driver. Further, the on plane arrangement can dampen vibrations as the surgical driver is being held by the larger arm muscles. Moreover, by stabilizing with the large arm muscles and using the wrists/fingers to manipulate, there can be less migration of the surgical driver, especially caused by unwanted jolts, as compared to an off plane arrangement, which uses a larger moment arm and thus is more susceptible to jerks/movements.

In some embodiments, the sleek form factor of the device can reduce packaging sizes, thus resulting in cost savings. Certain embodiments can ease the transition from manual surgical drivers to powered surgical drivers, can increase visibility of the tip and tissues into which the driving is occurring, and/or can reduce weight of the surgical driver which can mitigate user fatigue.

In some embodiments, the surgical driver **100** can be partially or fully cannulated and/or configured to be cannulated. This can allow the threading of a guidewire and/or k-wire (or other wire, the type of which is not limiting) through the surgical driver **100**. Further, the cannulation can allow for suction to be used in conjunction with the surgical driver **100**. The cannula can extend through the entirety of the surgical driver **100** (e.g., from back to front), or can include an aperture on a side of the body **102** that can lead to a tip (or near a tip) of the surgical driver **100**. The cannula can generally extend along (or be parallel with) a longitudinal axis of the surgical driver **100**.

Further, in some embodiments, the motor **12** itself within the surgical driver **100** can be cannulated as well. Thus, a cannula can extend through at least a portion of the motor of the surgical driver **100**. The motor **12** can be partially or fully cannulated and/or configured to be cannulated. The cannula can extend through the entirety of the motor **12** (e.g., from back to front), or can include an aperture on a side of the body **102** that can lead to a tip (or near a tip) of the surgical driver **100**. In some embodiments, the cannula can generally extend along (or be parallel with) a longitudinal axis of the motor in the surgical driver **100**. The cannulated motor can be used for a number of different applications including, for example, using a cannulated motor in a powered surgical device, using a cannulated motor in an on-plane powered surgical device, using a cannulated motor in an on-plane powered surgical device for clavicle applications, using a cannulated motor in an on-plane powered surgical device for spinal applications, using a cannulated motor in an on-plane powered surgical device for extremities, and/or using a cannulated motor in an on-plane powered surgical device for large bone applications. However, the cannulated motor can be used for other procedures as well, and the particular procedure is not limiting.

In some embodiments, the body **102** can include different shaped handles (or grips). The different handles can be used to replace a portion of the body **102**, and thus can be integrally formed with the body **102** in some embodiments. In some embodiments, different handles can be detachable from a proximal end of the body **102**, thus allowing a user to choose which particular handle suits the needs of a particular use (e.g., surgery). In some embodiments, the handles can be switched out during surgery by the surgeon. For example, the handles can have an attachment mechanism to the body **102**, such as through male/female threading, snaps, fasteners, or other non-limiting removable attachment devices.

The handles can be made from a number of different materials, such as metal, plastic, or rubber, and can come in a variety of different shapes. Handles can further include gripping features such as bumps or divots that make it easier for a user to control the handle. FIG. 3 illustrates example cross-sectional shapes of handles **30** that can be used with the surgical driver as disclosed herein. As shown, these handles **30** can have a generally “T” shape (FIG. 3 left) or generally circular or ball shape (FIG. 3 right). While these two particular handles **30** are illustrated, other handles can be used as well, such as generally “J” shaped, pistol grip, or closed ring handles, or otherwise. The particular handle shapes and dimensions of FIG. 3 are not limiting.

FIGS. 4-7 illustrate another example of the surgical driver **100**. The surgical driver **100** has a body **102** with a handle that can be grasped by a user. In the embodiment illustrated, the handle has a pistol grip configuration. In some implementations, the surgical driver **100** is approximately 7 inches

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long. The surgical driver **100** can have a power source, such as a battery **28**. The power source **28** can fit in the body **102**, such as in the handle.

FIG. **5** shows the bottom opening of the body **102**. The body **102** can have multiple cavities, such as a first cavity **42** that is designed to hold the battery **28** and a second cavity **44** that is designed to hold electronics, such as circuit boards. After the circuit boards are installed, a cover plate can be affixed to seal the second cavity **44** from moisture intrusion. Having the boards and battery both inserted into the handle allows the length and profile of the surgical driver **100** to be reduced.

FIG. **6** shows the battery **28** placed in the handle of the body **102** of the surgical driver **100**. In some implementations, the battery **28** is fully enclosed in the body **102**. A fully enclosed battery **28** can ensure that the battery **28** is not exposed to bio-material during operation. In some embodiments, the battery **28** is contained and/or sealed with a door. FIG. **7** shows the battery **28** inside the handle. The surgical driver design could include a mechanism that covers the battery **28** from the bottom and forces it up into the handle. This feature will ensure that the battery **28** engages the power contacts with the surgical driver **100** during use. In some embodiments, this mechanism may be hinged on one side to function like a trap door. In other embodiments, this mechanism may be pinned at one corner to rotate over or away from the cavity to allow the battery **28** to be inserted.

Various embodiments of the surgical driver **100** have a variety of operational characteristics. For example, some embodiments provide a maximum rotational speed (at no load) of at least about: 3,000 rpm, 4,000 rpm, 5,000 rpm, 6,000 rpm, 10,000 rpm, values between the aforementioned values, or other values. Some embodiments can slow the rotation of the drill bit **200** after a slowdown point has been reached. Certain such embodiments have a slowed speed (at no load) of less than or equal to about: 500 rpm, 600 rpm, 700 rpm, 800 rpm, 900 rpm, 1,000 rpm, 1,100 rpm, 1,200 rpm, values between the aforementioned values, or other values. Certain implementations of the surgical driver **100** can provide a torque on the drill bit **200** of at least about: 25 in-oz, 30 in-oz, 35 in-oz, 40 in-oz, 45 in-oz, values between the aforementioned values, or other values. Some embodiments of the surgical driver **100** can provide a torque on the drill bit **200** of at least: 25 N-cm, 30 N-cm, 35 N-cm, 40 N-cm, 45 N-cm, values between the aforementioned values, or other values.

Various embodiments of the surgical driver **100** include a forward input that a user can engage to instruct the surgical driver **100** to turn the drill bit **200** in a forward direction, such as in the direction to drill the drill bit **200** into the bone. For example, the forward input can be a switch, button, dial, trigger, slider, touchpad, or the like. Certain embodiments have multiple input members, such as a fast forward switch (e.g., the motor will spin at about 4100 RPM at no-load) and a slow forward switch (e.g., motor will spin at 500 RPM at no-load). Some implementations have a reversing input, which can instruct the surgical driver **100** to turn the drill bit **200** in a reverse direction, such as in the direction to remove the drill bit **200** from the bone. The reversing input can be similar to the forward input, such as the options described above. In some embodiments, engaging the reversing input causes the motor to spin at about 500 RPM at no-load. In certain implementations, the final rotational speed of the drill bit **200** is about 500 RPM. In some embodiments, the forward input and the override input are the same component. In some implementations, the surgical driver **100** can include an input device **106**, such as buttons, switches, or

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otherwise, that can allow a user to select a mode of operation. For example, the user can choose between a mode in which the driver stops drilling before breach (e.g., before the drill bit exits out the opposite side of the bone) occurs and a mode in which driver stops drilling after breach occurs.

In various embodiments, the surgical driver **100** includes components configured to adjust the torque data, such as by filtering the torque data, decreasing noise in a signal from a sensor **18** (e.g., a motor current sensor), or otherwise. For example, the surgical driver **100** can include one or more low-pass filters. The filters can be implemented in hardware and/or software. For example, in some embodiments, the filters comprise resistance capacitor circuitry. Certain embodiments include a software filter configured to filter out certain frequencies and/or levels of torque data. In various embodiments, the filtering components can facilitate a smoother torque curve. In some variants, the filtering components can reduce errors in the torque-limiting functionality that may otherwise be caused by noise and/or outlier measurements. In some embodiments, conversion of current, voltage, power, etc. to torque values (such as nm, inch ounces, etc.) can be performed with a look up table or a mathematical equation.

In some embodiments, the surgical driver can incorporate additional features that can identify and/or differentiate the starting torque for an already seated screw from that of a screw that has just started, such as through a higher initial torque value, which can inhibit or prevent the device from continuing to drive and potentially strip an already seated screw. Further disclosure regarding torque-limiting surgical devices (such as regarding dynamically determining and/or limiting torque when attempting to secure a plate against a bone with a screw in order to inhibit or prevent the screw from stripping or damaging the bone of a patient) can be found in U.S. Pat. No. 10,383,674 filed on Jun. 6, 2017, which is hereby incorporated by reference in its entirety. Any of the features described in the '674 patent can be incorporated in the systems, devices, and methods disclosed herein.

#### Substrate Identification and/or Differentiation Overview

In some embodiments, data inputs (e.g., measurements performed during a portion or throughout a drill bit drilling procedure) can be used by a surgical driver **100** to make certain determinations. For example, the surgical driver **100** can be configured to use the data inputs to distinguish between and/or identify different types of tissues that the drill is being driven into. This can be called "tissue differentiation."

The data inputs can come from, for example, motor current and/or speed, though other methods of torque measurement can be used as well. In some embodiments, the data inputs comprise a measured torque, which can be data that is derived from or indicative of the torque being supplied by the surgical driver **100**. In some implementations, the data inputs comprise current and/or voltage measurements, and one or more algorithms or data tables can be used to convert the inputs into torque values.

As discussed in more detail below, in some embodiments, the surgical driver **100** can use the data inputs, and/or changes in the data inputs, to determine a particular tissue type that the surgical driver **100** is driving the drill bit **200** into. For example, the surgical driver **100** can be configured to discern whether the drill bit **200** is being driven into soft tissue or bone based on the data inputs and/or changes in the data inputs. Further, the surgical driver **100** can be configured to discern between different soft tissues or different

bone types or portions of bone (e.g., cortical and cancellous) based on the data inputs and/or changes in the data inputs.

In some embodiments, the data inputs and/or the determinations can be used to adjust operation of the surgical driver **100**. For example, an algorithm (e.g., a discrete torque analysis algorithm) can use the data inputs to manage the drill bit velocity of the surgical driver **100**. The algorithm can be used to adjust other characteristics/functionalities of the surgical driver **100**, such as voltage, current, rotational speed of the drill bit, and/or power supplied to the motor. In some embodiments, the measured torque and/or changes in the measured torque can be used to control driving of the drill bit **200**, such as stopping operation of the motor, changing the driving velocity of the drill bit **200**, or other changes.

In some embodiments, the changes in torque can be presented (e.g., shown or displayed) to a user. For example, embodiments of the surgical driver **100** can include one or more indicators, such as lights or sounds, which indicate the drill bit **200** is being driven in a particular torque range and/or that the drill bit **200** is being driven in a particular tissue layer or type. For example, a first indicator can activate when the drill bit **200** is being driven into a first tissue type and/or layer, and a second indicator can activate when the drill bit **200** is being driven into a second tissue type and/or layer. The surgical driver **100** can include a display (e.g., an electronic screen) that displays certain information, such as the torque being applied to the drill bit, the type of tissue the drill bit is being driven into, or otherwise. The display can be located directly on the surgical driver **100**, or can be through another connected visual device, such as a TV screen or monitor in which the surgical driver **100** is connected to, for example wirelessly or wired.

As discussed in detail below, the torque and/or changes in torque can be measured in a number of different ways. For example, torque measurements can be taken during some or all (and consistently or inconsistently) of the drill bit drilling procedure. In some implementations, variations between consecutive measurements can be provided to the user. In some embodiments, an alert is provided to the user when the measured torque is outside of a certain range or beyond a threshold. This threshold may be created, for example, by a user inputting a particular torque profile into the surgical driver **100** for a particular procedure. For example, the torque profile could be for the drilling of a drill bit **200** into a clavicle bone and could include pre-programmed thresholds for that particular procedure. Further, changes in the torque or other aspects of the torque, such as the first or second derivatives of torque measurements, may be provided to the user.

The surgical driver **100** can use tissue differentiation in a variety of applications and environments. For example, the surgical driver **100** can be configured to distinguish and/or identify different tissue types during a clavicle orthopedic surgery. However, other types of surgeries or procedures are possible.

Further disclosure regarding certain features related to torque-limiting surgical drivers can be found in U.S. Pat. No. 9,265,551, filed on Jul. 16, 2014 and U.S. Pat. No. 10,383,674, filed on Jun. 6, 2017, which are hereby incorporated by reference in their entireties. Any of the features (for example, certain torque-limiting features) disclosed in the '551 Patent and/or the '674 Patent can be used in conjunction with the surgical drivers disclosed herein.

The torque used to drill a drill bit through a given bone can vary significantly. One factor that affects the amount of torque required to drill the drill bit through a bone is the

density of the bone, which can change based on the patient's age, gender, disease, and other factors. Typically, the denser the bone, the greater the force required to drill the drill bit. Additionally, density can change depending on the location of bone within the body.

Several torque-limiting methods, algorithms, and components are described below. Any method, algorithm, or component disclosed anywhere in this specification can be used in conjunction with any other method, algorithm, or component disclosed anywhere in this specification, or can be used separately.

#### "Anti-Plunge" Torque-Limiting Applications

As discussed above, in certain surgical procedures, medical professionals (for example, surgeons) utilize hand-powered instruments to drill into a bone of a patient. However, after drilling through an entry side of the bone (e.g., a first cortical portion of a bone), it can be difficult to determine when to stop the motor so as to inhibit or prevent "plunging" of the drill bit into tissue proximate an exit side of the bone, which can cause significant damage to the tissue. Embodiments of the surgical driver described herein can be configured to limit or stop operation of the motor and/or rotation of the drill bit when the surgical driver detects that the drill bit has breached or is close to breaching a bone. For example, embodiments of the surgical driver described herein can limit or stop operation of the motor and/or rotation of the drill bit: (1) when the surgical drill detects that the drill bit is drilling at or through a location close to an exit point or region of the bone; and/or (2) when the surgical drill detects that the drill bit breaches (exits), or has breached, the bone. With respect to "(1)" (also referred to herein as a "pre-breach" stage), some embodiments of the surgical driver described herein can limit or stop operation of the motor and/or rotation of the drill bit: (a) when the surgical drill detects that the drill bit has transitioned from a softer portion of bone (e.g., cancellous portion) to a harder portion of bone (e.g., cortical); and/or (b) when the surgical drill detects that the drill bit is currently located (and/or drilling) within a second layer of a harder portion of bone (e.g., cortical) and is thus close to an exit side of the bone. With respect to "(2)" (also referred to herein as a "post-breach" stage), some embodiments of the surgical driver described herein can limit or stop operation of the motor and/or rotation of the drill bit when the surgical drill detects that the drill bit breaches (exits), or has breached, the bone.

FIG. 8 illustrates a simplified cross-section of a bone **202** of a patient. For example, bone **202** can be a clavicle, among others. Drill bit **200**, which can be any type of drill bit capable of engaging and/or drilling through bone **202**, is shown proximate, but spaced away from bone **202**. Drill bit **200** can be received and/or driven by drive head **104** and/or motor **12** as discussed previously with respect to surgical driver **100**. In some surgical scenarios, a medical professional may desire to drill out and/or through bone **202** in order to clear material for a screw and/or plate to be utilized to repair the bone **202** or a portion thereof. As discussed above, the typical approach is to operate a surgical driver **100** so as to drill through a first side of the bone **202** with drill bit **200** (for example, at point A of bone **202**) and stop immediately when the drill bit **200** breaches through a second, opposite side of the bone **202** (for example, at point D). However, it is difficult for medical professionals to know where the drill bit **200** is within the bone and/or when to stop the motor of the surgical driver. As discussed above, the ability to detect when the drill bit **200** has breached or is close to breaching the bone **202** is important to inhibit or prevent damage to nearby tissue proximate bone **202**.

Surgical driver **100** can utilize various methods and/or algorithms to detect the location of the drill bit **200** within bone **202** and stop rotation of the drill bit **200** prior to breaching bone **202** and/or plunging into or through tissue proximate the breaching point of bone **202**. Surgical driver **100** can measure torque values at various sequential times in order to monitor and/or detect the position of drill bit **200** within bone **202**. For example, in certain embodiments, a measured amount of torque (or current drawn by the motor, or other methods of determining rotation/torque discussed herein) is sampled at a sampling rate, such as about every: 2 milliseconds (ms), 5 ms, 10 ms, 20 ms, 30 ms, or any value therebetween, or any range bounded by any combination of these values, although other values outside these ranges are possible. The torque and time data can be stored in memory **24** of the surgical driver **100**. This can facilitate monitoring the change in the torque relative to time (e.g., a first derivative of the torque) and/or monitoring torque at discrete intervals defined by the sampling time (for example, every 10 ms). As noted above, the torque can be directly proportional to the motor power required to drill the drill bit **200**. In several embodiments, the torque at a given time is determined by the controller **20**, which receives a signal from the sensor **18** indicative of the current drawn by the motor **12**.

#### Overview of Exemplary Torque-Limiting Procedures

FIG. **9** illustrates an exemplary method and/or algorithm **201** of torque-limiting drilling in order to inhibit or prevent plunging of drill bit **200** through bone **202** and resulting damage to nearby tissue. FIGS. **10-13** illustrate further variations and/or details of exemplary method and/or algorithm **201**.

The method **201** can begin after the driver **100** is on (e.g., energized). At block **210**, the surgical driver **100** determines whether the motor **12** is on. Motor **12** can be turned on in response to a user activating an input (e.g., a button or switch) and the controller **20** instructing that power be supplied to the motor **12**. The power can be used to begin turning the drill bit **200** received within and/or secured to the drive head **104**. As shown in FIG. **9**, if block **210** determines that motor **12** is not on, the method **201** can end. As shown in block **212**, if it is determined that the motor **12** is on, the surgical driver **100** can begin collecting and/or storing torque values at a sampling rate, such as at 10 ms intervals as discussed above. The surgical driver **100** can collect the torque values via sensor **18**, such as a sensor that can measure the amount of current being drawn by the motor **12**. This current draw data can be used to determine the amount of torque because the current drawn by the motor **12** is generally proportional to the amount of torque that the motor is applying to drill bit **200** driven by the driver **100** (e.g., via drive head **104**). The measured/collected torque values can be stored in memory **24** of driver **100**.

As shown in block **214**, the surgical driver **100** can (e.g., via controller **20** and/or processor **22**) compare each collected and/or stored torque value to a first threshold  $T_{Thresh1}$ . This can be used to determine whether the drill bit **200** is engaging and/or drilling through bone **202**, as opposed to merely rotating in air (e.g., free-spinning). The torque values detected when drill bit **200** is free-spinning through air are generally significantly lower than torque values detected when drill bit **200** is engaging and/or drilling through bone **202**. In some implementations, the first threshold  $T_{Thresh1}$  can be 0.035 in-oz, 0.036 in-oz, 0.037 in-oz, 0.038 in-oz, or 0.039 in-oz, or any range bounded by any combination of these values, although other values are possible. As shown

in block **216**, if a given torque value is greater than or equal to the first threshold  $T_{Thresh1}$ , the controller **20** can collect/store each of such occurrence as a “count,” the benefits of which are described further below. In some cases, the number of occurrences/times that measured torque values are greater than or equal to the first threshold  $T_{Thresh1}$  can provide an indication of the thickness of the bone **202**.

In some embodiments, the controller **20** tracks the torque data that meets certain requirements. For example, in the embodiment illustrated in FIG. **9**, at block **218**, the controller **20** can determine and store a sum of the torques that are greater than or equal to the first threshold  $T_{Thresh1}$ .

In various implementations, the controller **20** can use the torque data to deduce a location of the drill bit **200**. For example, at block **220**, the controller **20** can run a drill bit location analysis to determine the location of the drill bit **200** with respect to bone **202**, as will be described further below. In some implementations, the controller **20** can run the drill bit location analysis regardless of whether a given torque value is greater than or equal to first threshold  $T_{Thresh1}$  at block **214**. Thus, blocks **214**, **216**, and/or **218** are not requirements for the operation of block **220**. As discussed in more detail below, after the drill bit location analysis is conducted at block **220**, the surgical driver **100** can be configured to determine whether to change an operating characteristic of motor **12**. For example, the surgical driver **100** can be configured to determine whether to reduce or stop rotation of the drill bit **200** (via motor **12** and/or drive head **104**) in response to a determination resulting from the analysis conducted at block **220** and to implement such a change. Such drill bit location analysis can include determining whether measured torque value(s) satisfy a criteria that indicates that the drill bit **200** has breach a bone or that is indicative that the drill bit **200** is close to breaching the bone. As shown in FIG. **9**, if measured torque value(s) do not satisfy a criteria indicating that the drill bit **200** has breached or is close to breaching a bone, the method can return to block **210** and collect additional torque values.

#### Drill Bit Location/Torque Criteria Analysis

FIG. **10** illustrates block **220** in more detail. As discussed above, torque values can be collected at various sampling rates, for example, at every 10 ms. Before torque values over a given time period are used to determine the location of drill bit **200** within bone **202**, it can be beneficial to ignore or discard a certain amount of initial values. For example, when motor **12** of surgical driver **100** is first turned on, there is a fair amount of “noise” originating from gears of the motor **12** which may produce variable torque values that do not represent engagement of the drill bit **200** with bone **202**. Thus, at block **222**, the controller **20** discards a first set or group of torque values before proceeding further with analysis. The amount of initial torque values that the controller **20** ignores or deletes can be equal to one, two, three, or four initial torque values, although other values are possible.

After block **222** is completed, controller **20** carries out blocks **224** and **226**, each of which will be described in more detail below. At a high level, blocks **224** and **226** can determine the location of drill bit **200** within bone **202**. More specifically, block **224** can determine whether the drill bit **200** is drilling, or has drilled, through or in the first cortical portion of bone **202**. For example, with reference to FIG. **8**, block **224** can determine whether the drill bit **200** is drilling, or has drilled, through or in the first cortical portion of bone **202** between points A and B of bone **202**. Similarly, block **226** can determine the location of drill bit **200** with respect to the second cortical portion of bone **202** (for example, the portion of bone **202** between points C and D in FIG. **8**).



As will be discussed in more detail below, determining the location of drill bit **200** with respect to the second cortical portion of bone **202** can involve determining, with the surgical driver **100** whether the drill bit **200** is in a “pre-breach” stage (e.g., close to breaching the bone) or whether the drill bit **200** is in a “post breach” stage (e.g., has breached the bone). Surgical driver **100** can determine that the drill bit **200** is in a pre-breach stage by determining whether the drill bit **200** is drilling at or through a location close to an exit point or region of the bone **202** (such as exit point D in FIG. **8**). Surgical driver **100** can determine that the drill bit **200** is in a post-breach stage by determining whether the drill bit **200** is breaching (e.g., exiting), or has breached, an exit point or region of bone **202** (such as exit point D in FIG. **8**). With respect to “pre-breach” and as further discussed below, in block **226** the surgical driver **100** can determine whether drill bit **200** has recently transitioned from the interior cancellous portion of the bone **202** to a second cortical portion of bone **202** and/or to determine whether drill bit **200** is currently drilling through this second cortical portion of bone **202**. As discussed in more detail below, after the surgical driver **100** determines that the drill bit **200** is in a “pre-breach” or “post-breach” stage as the particular implementation is configured, the surgical driver **100** can change an operating characteristic of motor **12** in response at block **240**. For example, the surgical driver **100** can shut off the motor **12** or decrease a rotation of the drill bit **200** in response to either of such determination(s).

#### Drill Bit Location with Respect to First Cortical Portion of Bone

FIG. **11** illustrates block **224** in more detail. As discussed above, a first group or set of torque samples collected (e.g., measured) by the surgical driver **100** can be ignored or discarded before further analysis is carried out according to block **220**. This first group of samples can be the first three or four torque samples (e.g., torque values one through three or four), for example. As shown, at block **224a**, a second group or set of torque samples can be collected and analyzed to determine whether the drill bit **200** is drilling, or has drilled, through or in the first cortical portion of bone **202**. Such second group of torque samples can include a plurality of torque samples, such as five torque samples. For example, the second group of torque samples can be the fifth, sixth, seventh, eighth, and ninth torque samples and can follow the first group of discarded torque samples. Controller **20** can keep track of the maximum torque values experienced within the second group of torque samples, the benefits of which are described further with respect to block **226** below.

At block **224a**, the second group of torque samples or a portion thereof (for example, torque samples 5-9) can be analyzed and/or compared to determine whether a difference between consecutive torque values within this second group is greater than or equal to a second threshold  $T_{Thresh2}$ . For example, controller **20** can determine whether a difference between a 7<sup>th</sup> and a 6<sup>th</sup> torque value (numbered consecutively with respect to the first group of torque values) within the second group is greater than or equal to the second threshold  $T_{Thresh2}$  and/or whether a difference between a 6<sup>th</sup> and a 5<sup>th</sup> torque value (numbered consecutively with respect to the first group of torque values) within the second group is greater than or equal to the second threshold  $T_{Thresh2}$ . If one or both of such differences is greater than or equal to the second threshold  $T_{Thresh2}$ , then block **224a** is affirmative. An affirmative block **224a** can be indicative that the drill bit **200** is drilling through a hard portion of the bone **202**, such as the first cortical portion of bone **202** at or between points A and B as shown in FIG. **8**. If block **224a** is affirmative, the

surgical driver **100** can record and/or store the occurrence of such threshold exceedance as an event at block **224c** (in memory **24**). This can provide an indicator for the method that the first cortical portion of bone **202** has been encountered. As illustrated, the surgical driver **100** can analyze (e.g., compare) additional torque values within this second group, for example, until all the torque values within this second group have been analyzed according to blocks **224a-224g**. For example, as shown in FIG. **11**, if either of block **224a** or block **224b** are affirmative and lead to block **224c**, the controller **20** can move to block **224h** and determine whether there are additional torque values in the second group to be analyzed. If block **224h** is affirmative, the controller **20** can return to block **224a** and analyze remaining torque values according to blocks **224a-224c** until block **224h** is answered in the negative. Alternatively, in some embodiments, if block **224a** is affirmative, the controller **20** of surgical driver **100** does not move to block **224h** but instead moves from block **224c** to block **226** (see block **224g**), where additional analysis can be carried out as discussed further below. If block **224a** is not affirmative, the method/algorithm can move to block **224b**, where additional analysis can be carried out as described further below.

In some embodiments, the controller **20** can determine that the first cortical portion (e.g., between points A and B in FIG. **8**) of bone **202** has actually been drilled through (e.g., through point B in FIG. **8**). For example, in some variants, controller **20** is configured to detect that the drill bit **200** has passed through the first portion of cortical bone by detecting a decrease in the torque values. Certain embodiments are configured to determine that the first cortical portion of bone **202** has been bored through by: (1) recording an event at block **224c**; (2) determining that blocks **224a** and **224b** return a “No” for subsequently collected torque values; and (3) analyzing both such results together (e.g., recognizing that “(1)” and “(2)” can indicate that an exit point of the first cortical portion has been drilled through).

The second threshold  $T_{Thresh2}$  can be 0.00195 in-oz, 0.00196 in-oz, 0.00197 in-oz, 0.00198 in-oz, 0.00199 in-oz, 0.002 in-oz, 0.00201 in-oz, 0.00202 in-oz, 0.00203 in-oz, 0.00204 in-oz, or 0.00205 in-oz, or any range bounded by any combination of these values, or any value within a range bounded by any of these values, although other values are possible.

At block **224b**, the second group of torque samples (e.g., torque samples 5-9) or a portion thereof can be analyzed and/or compared to determine whether a difference between non-consecutive torque values within this second group is greater than or equal to a third threshold  $T_{Thresh3}$ . For example, one or more non-consecutive torque samples within the second group that are separated by one intermediate torque sample can be compared to determine whether a difference therebetween is greater than or equal to the third threshold  $T_{Thresh3}$ . For example, controller **20** can determine whether a difference between a 9<sup>th</sup> and a 7<sup>th</sup> torque value is greater than or equal to the third threshold  $T_{Thresh3}$  and/or whether a difference between a 7<sup>th</sup> and a 5<sup>th</sup> torque value is greater than or equal to the third threshold  $T_{Thresh3}$ . If one or both of such differences is greater than or equal to the third threshold  $T_{Thresh3}$ , this can be indicative that the drill bit **200** is drilling through the hard portion of the bone **202**, such as the first cortical portion of bone **202** at or between points A and B as shown in FIG. **8**. If one or both of such differences is greater than or equal to the third threshold  $T_{Thresh3}$ , the surgical driver **100** can record and/or store the occurrence of such threshold exceedance as an event at block **224c** (in memory **24**) which indicates that the first cortical portion of

bone 202 is being drilled through. If one or both of such differences is greater than or equal to the third threshold  $T_{Thresh3}$ , at block 224h the surgical driver 100 can determine whether there are additional torque values within the second group to be analyzed. If block 224h is affirmative, the controller 20 can return to block 224a and analyze remaining torque values according to blocks 224a-224c until block 224h is answered in the negative. Alternatively, in some embodiments, if block 224b is affirmative and an event is recorded at 224c, the controller 20 of surgical driver 100 does not move to block 224h but instead moves from block 224c to block 226 (see block 224g), where additional analysis can be carried out as discussed further below.

If a difference between non-consecutive torque values (e.g., 2 values separated by one intermediate value) within this second group is not greater than or equal to the third threshold  $T_{Thresh3}$ , this can indicate either: (a) that the drill bit 200 has not engaged bone 202 (e.g., is free-spinning); or (b) that the drill bit 200 has already drilled through the first cortical portion of bone 202 (e.g., through point B of FIG. 8). To determine which of “(a)” or “(b)” is true, the controller 20 can check, at block 224d, whether an event at block 224c was previously recorded. If the controller 20 determines that event 224c was previously recorded, controller 20 determines, at block 224e, that the first cortical portion of bone 202 has already been drilled through (e.g., through point B in FIG. 8). In such cases, the drill bit 200 can be drilling through the softer, cancellous portion of bone 202. Alternatively, if the controller 20 determines that event 224c was not previously recorded and all of the second group of torque values have been collected (e.g., measured), the controller 20 determines, at block 224f, that the drill bit 200 is “free-spinning.” In some embodiments, the controller 20 is configured to move to block 240 if it determines that the drill bit is free-spinning, which can stop or reduce rotation of the drill bit 200. This can advantageously conserve power (e.g., drawn from a power source) and/or processing power that would otherwise be utilized to further operate the motor 12 and carry out torque value analysis.

In some embodiments, the third threshold  $T_{Thresh3}$  can be greater than the second threshold  $T_{Thresh2}$ . The third threshold  $T_{Thresh3}$  can be 0.00215 in-oz, 0.00216 in-oz, 0.00217 in-oz, 0.00218 in-oz, 0.00219 in-oz, 0.0022 in-oz, 0.00221 in-oz, 0.00222 in-oz, 0.00223 in-oz, 0.00224 in-oz, or 0.00225 in-oz, or any value within a range bounded by any of these values, although other values are possible.

As discussed above, the controller 20 can move to block 226 after determining a “Yes” result from block 224a or 224b, or can wait to move to block 226 until all the torque values in the second group have been analyzed according to blocks 224a and 224b (e.g., via a determination at block 224h). As discussed above, at block 226, additional analysis can be carried out to determine where the tip of the drill bit 200 is with respect to the interior (e.g., cancellous) portion of bone 202 and/or the second cortical portion of bone 202 (e.g., at or between points C and D in FIG. 8). In some embodiments, if an event was recorded at block 224c (e.g., drill bit 200 was recorded as drilling through the first cortical portion of bone 202) and/or the controller 20 determined that the drill bit 200 has already drilled through the first cortical portion of bone 202 (block 224e), such determination can be advantageously used in further analysis when attempting to determine whether the drill bit 200 is currently in, or has recently drilled through the second cortical portion of bone 202 (e.g., at or between points C and D in FIG. 8), as discussed in more detail below.

Blocks 224a and 224b provide two methods by which drilling of the drill bit 200 through the first cortical portion of bone 202 can be detected. Comparing differences between one or more (or one or more sets of) consecutive torque values within the second group of torque samples (as done in block 224a) can be advantageous when drilling through thinner bone cross-sections (and, for example, thinner cortical portions of such bones). Comparing one or more (or one or more sets of) non-consecutive torque values separated by an intermediate torque value within the second group (as done in block 224b) can be advantageous when drilling through thicker bones or where a surgeon angles the drill bit 200 at an angle different than perpendicular to a surface of bone 202 (for example, at angles within 15 degrees from an axis perpendicular to such bone surface). Incorporating both blocks 224a and 224b advantageously allows controller 20 of surgical driver 100 to be used for both thin and thick bones and/or to predict whether the drill bit 200 is drilling through or in the first cortical portion of bone 202 (for example, between points A and B of bone 202 as shown in FIG. 8).

#### Drill Bit Location with Respect to Second Cortical Portion of Bone

As discussed above, the controller 20 can move to block 226 after block 224g or block 224e. As discussed above, at a high level, block 226 can aid in determining the location of drill bit 200 with respect to the second cortical portion of bone 202 (for example, the portion of bone 202 between points C and D in FIG. 8). As also discussed above, determining the location of drill bit 200 with respect to the second cortical portion of bone 202 can involve determining, with the surgical driver 100: (1) when the drill bit is drilling at or through a location close to an exit point or region of the bone 202 (such as exit point D in FIG. 8); and/or (2) when the drill bit breaches (exits), or has breached, an exit point or region of bone 202 (such as exit point D in FIG. 8). With respect to “(1)” and as further discussed below, in block 226 the surgical driver 100 can determine whether drill bit 200 has recently transitioned from the interior cancellous portion of the bone 202 to a second cortical portion of bone 202 (for example, has transitioned through an entry point C in FIG. 8) and/or to determine whether drill bit 200 is currently drilling through this second cortical portion of bone 202 (for example, is drilling through the second cortical portion and is located somewhere between point C and D in FIG. 8). Some embodiments of the surgical driver described herein can limit or stop operation of the motor and/or rotation of the drill bit when the surgical driver determines “(1)” (also referred to herein as a “pre-breach” stage). Some embodiments of the surgical driver described herein can limit or stop operation of the motor and/or rotation of the drill bit when the surgical driver determines “(2)” (also referred to herein as a “post-breach” stage).

As discussed above, the controller 20 of surgical driver 100 can collect torque values measured and/or communicated by sensor 18 at a sampling rate. As also discussed, a first group of torque samples can be discarded (see FIG. 10 and block 222) and a second group of torque samples can be utilized to determine whether drill bit 200 is drilling in and/or has drilled through the first cortical portion of bone 202 (see FIGS. 10-11 and block 224). Additionally, a third group of torque samples can be utilized to carry out the analysis of block 226. As a non-limiting example, the first group of samples can include four samples (for example, numbered samples 1-4), the second group of samples can include five samples (for example, numbered samples 5-9),

and the third group of samples can include ten or more samples (for example, 16 samples numbers 10-25).

In block **226**, the third group of torque samples can be collected. The controller **20** can analyze (e.g., compare) one or more torque values within the third group of torque samples. This can aid in determining whether drill bit **200** has recently transitioned from the interior cancellous portion of the bone **202** to a second cortical portion of bone **202** and/or whether drill bit **200** is currently drilling through this second cortical portion of bone **202**. Before carrying out such comparisons, as shown in FIG. **12**, controller **20** can determine whether there have been a sufficient number of bone-drilling or bone-engaging torque samples at a given point in time (e.g., after a given amount of torque values have been sampled at a sampling rate). As discussed previously with reference to FIG. **9**, controller **20** can track how many measured torque values are greater than or equal to the first threshold  $T_{Thresh1}$ , and where a given torque value is greater than or equal to such first threshold  $T_{Thresh1}$ , this indicates that that torque value represents a value experienced when the drill bit **200** is drilling into a material other than air (e.g., bone), which represents a “bone-engaging torque sample.” At block **226a**, if the number of bone-engaging torque samples is greater than or equal to a threshold percentage  $P_{Thresh1}$  of the total number of torque values measured, a certain confidence level is achieved and the controller **20** continues with the analysis described below. Such threshold percentage  $P_{Thresh1}$  can be 60%, 70%, 80%, 90%, 95%, 96%, 97%, 98%, or 99%, for example. As shown by block **226b**, if the number of bone-engaging torque samples is less than such threshold percentage  $P_{Thresh1}$ , the controller **20** can halt further analysis and require that more torque samples be measured which are greater than or equal to the first threshold  $T_{Thresh1}$ . For example, in some variants, after block **226b**, the method returns to block **210** for further analysis and value collection.

If the number of bone-engaging torque samples is greater than or equal to such threshold percentage  $P_{Thresh1}$ , the controller **20** carries out block **226c**. Block **226c** can facilitate determining whether the drill bit **200** has recently transitioned from the interior cancellous portion of the bone **202** to a second cortical portion of bone **202** (for example, has recently transitioned through point C in FIG. **8**). In some embodiments, to “capture” or detect such transition, at block **226c**, controller **20** compares a consecutive pair of torque values (e.g., from the third group of torque values) to determine whether a difference between such pair is greater than or equal to a fourth threshold, referred to herein as “StepDelta” or “ $\Delta_{Step}$ .” If such difference is greater than or equal to  $\Delta_{Step}$ , this can demonstrate a large rate of change between consecutive torque values that is indicative of transitioning from a cancellous portion to a cortical portion of bone **202**.  $\Delta_{Step}$  can be determined based upon statistics of past torque values (for example, one or more torque values in the first, second, and/or third group). For example,  $\Delta_{Step}$  can be equal to a second threshold percentage  $P_{Thresh2}$  of the average of all the torque values measured at a given point in the analysis. The average torque value “ $T_{Avg}$ ” can be equal to the sum of all torque values previously measured, stored, and/or recorded divided by the number of bone-engaging torque samples (e.g., the number of torque samples that were greater than or equal to the first threshold  $T_{Thresh1}$ ). In some embodiments,  $T_{Avg}$  does not include discarded torque values, such as those from block **222**.

If a difference between a consecutive pair of torque values from the third group of torque samples is greater than or equal to  $\Delta_{Step}$ , this can indicate that there has been a

significant rate of change of torque values between such consecutive torque values, which in turn can indicate that drill bit **200** has recently transitioned from cancellous bone to a second cortical portion of bone **202** (for example, through point C shown in FIG. **9**). If this is true, controller **20** moves to block **226d**, which is described in more detail below. For example, as discussed below, in some embodiments, if a difference between a consecutive pair of torque values from the third group of torque samples is greater than or equal to  $\Delta_{Step}$ , the controller **20** operates to stop or reduce the rotation of the drill bit **200** (e.g., if it is desirable to move to block **240** before the drill bit **200** breaches the bone **202**). If such difference between a consecutive pair of torque values from the third group of torque samples is less than  $\Delta_{Step}$ , the controller **20** moves on to block **226e**, which is further described below. The second threshold percentage  $P_{Thresh2}$  can be 8%, 9%, 10%, 11%, 12%, 13%, 14%, or 15%, or any percentage within a range bounded by any of these percentages, although other values are possible.

At block **226e**, controller **20** can analyze one or more torque values within the third group of samples to determine whether drill bit **200** is currently drilling through the second cortical portion of bone **202** (for example, between points C and D in FIG. **8**). Conducting the step of block **226e** after block **226c** where block **226c** yields a “No” (e.g., a difference between a consecutive pair of torque values from the third group of torque samples is less than  $\Delta_{Step}$ ) can be advantageous where stopping rotation of drill bit **200** prior to breaching the bone **202** is desirable. For example, in some cases it may be difficult for two consecutive torque values in the third group to “capture” the cancellous-to-cortical transition point (for example, point C in FIG. **8**) because such two torque values are measured at discrete time intervals (for example, every 10 ms). Such cancellous-to-cortical transition point may not “fall within” such two consecutive torque values/measurements. In these cases, providing an alternative method for detecting whether the drill bit **200** is close to breaching bone **202** (for example, is drilling through the second cortical portion between points C and D in FIG. **8**) can be advantageous.

At block **226e**, controller **20** compares a given (for example, current or most recent) torque value with a fifth threshold, referred to herein as “Torque $_{\Delta}$ ” or “ $T_{\Delta}$ .” If such current (e.g., most recent) torque value is greater than or equal to  $T_{\Delta}$ , this can indicate that the drill bit **200** is currently drilling through the second portion of cortical bone.  $T_{\Delta}$  can be equal to the average torque value  $T_{Avg}$  plus the  $\Delta_{Step}$  (both discussed previously).  $T_{\Delta}$  thus represents a high torque value relative to previously recorded (e.g., measured) torque values.

If a given (e.g., current) torque value is greater than or equal to  $T_{\Delta}$ , controller **20** can move to block **226f** to conduct an additional test as to whether the given torque value is close to the maximum torque value recorded (e.g., measured) so far,  $T_{Max}$ . More specifically, at block **226f**, controller **20** can determine a difference between a current (e.g., recent) torque value and  $T_{Max}$ , and further determine whether such difference is greater than or equal to a sixth threshold  $T_{Thresh6}$ . In some embodiments, controller **20** determines whether an absolute value of the difference between a current torque value and  $T_{Max}$  is greater than or equal to the sixth threshold  $T_{Thresh6}$ . The sixth threshold  $T_{Thresh6}$  can be 0.00295 in-oz, 0.00296 in-oz, 0.00297 in-oz, 0.00298 in-oz, 0.00299 in-oz, 0.003 in-oz, 0.00301 in-oz, 0.00302 in-oz, 0.00303 in-oz, 0.00304 in-oz, or 0.00305 in-oz, or any range bounded by any combination of these

values, or any value within a range bounded by any of these values, although other values are possible.

If controller **20** determines that a difference (or absolute value of a difference) between a current torque value and  $T_{Max}$  is greater than or equal to the sixth threshold  $T_{Thresh6}$ , controller **20** moves to block **226d**, which is discussed further below. Alternatively, if controller **20** determines that such difference (or absolute value of a difference) is less than the sixth threshold  $T_{Thresh6}$ , controller **20** moves to block **226g**.

At block **226g**, controller **20** can check whether an event was recorded according to block **224c** (indicating that the drill bit **200** was drilling through the first cortical portion) and/or can check the results of the determination made at block **224d** (whether the drill bit **200** actually drilled through the first cortical portion of bone). If the controller **20** previously determined that drill bit **200** drilled in or through the first cortical portion of bone **202**, controller **20** can move from block **226g** to block **226d**, which is described further below. Block **226g** can be advantageous because, even if controller **20** determines at block **226f** that a current (e.g., recent) torque value is not close enough (e.g., within the sixth threshold  $T_{Thresh6}$ ) to  $T_{Max}$ , so long as the controller **20** recognizes that the first cortical portion has already been drilled in or through, the current (e.g., recent) torque value is sufficiently high (as determined by block **226e**) such that it indicates that the drill bit **200** is currently drilling through the second cortical portion of bone **202**. Alternatively, if controller **20** analyzes the results of block **224d** and determines that the first cortical portion of bone **202** was not drilled in or through (e.g., that block **224f** was determined), controller **20** can continue to collect and analyze subsequent torque values and carry out one or more of blocks **226a-226g** thereafter.

In some embodiments, when results of the determinations of block **226c** and/or blocks **226e-226g** lead to block **226d**, that can indicate that the drill bit **200** is drilling through the second cortical portion of bone **202**. In response, the controller **22** can communicate with the motor **12** to stop or reduce rotation of drill bit **200**. For example, at block **226c**, when the controller **20** determines that drill bit **200** has recently transitioned from cancellous bone to a second cortical portion of bone **202** (for example, through point C shown in FIG. **8**), the controller **20** of surgical driver **100** can communicate with the power source **28** and/or the motor **12** to turn motor **12** off and/or stop or reduce rotation of drill bit **200** (e.g., the controller **20** can move on to block **240**). As another example, when the controller **20** determines that the drill bit **200** is currently drilling through the second cortical portion of bone **202** at block **226e** and either of block **226f** or block **226g** result in a “Yes,” the controller **20** of surgical driver **100** can communicate with the power source **28** and/or the motor **12** to turn motor **12** off and/or stop or reduce rotation of drill bit **200** (e.g., the controller **20** can move on to block **240**). Alternatively, in some embodiments, as shown in FIG. **12**, at block **226d**, controller **20** can conduct further analysis and/or measure additional torque values. For example, where it is desirable to stop or reduce rotation of drill bit **200** after (as opposed to before) breaching bone **202**, controller **20** can measure additional torque values and/or conduct further analysis to detect when such breach occurs. Such analysis is described below with respect to FIG. **13**.

#### Drill Bit Breach

FIG. **13** illustrates block **230** in more detail. At a high level, block **230** can facilitate determining the location of the drill bit **200** with respect to a “breach” (exit) point or region

of the second cortical portion of bone **202** as illustrated by point D in FIG. **8**. To determine whether the drill bit **200** has breached through such point or region, it can be beneficial to compare current/recent measured torque values with previous torque values collected when drill bit **200** is drilling through the second cortical portion of bone **202**. For example, as drill bit **200** is drilling through the second cortical portion, if measured torque values appear to decrease or fall below some threshold, this can be indicative that drill bit **200** has breached through bone **202** (for example, through point D in FIG. **8**). In such cases, controller **20** can be configured to move to block **240** and, for example, reduce or stop rotation of drill bit **200**.

With reference to block **230a**, in some embodiments, for each torque value within the third group that results in a “Yes” for block **226c**, block **226e** and block **226f**, or block **226g**, controller **20** and/or processor **22** can determine a rolling average of such torque values. For example, if 5 torque samples from the third group of samples result in a “Yes” for block **226c**, block **226e** and block **226f**, or block **226g**, (representing drilling through the second cortical portion of bone **202**), controller **20** and/or processor **22** can determine an average of these torque values, store such average, and update such average after each subsequent one of these 5 samples. Such average can advantageously be used as a breach threshold  $T_{Breach}$  to determine whether the drill bit **200** has breached the bone **202**. Controller **20** can carry out block **226** and block **230a** for each of the third group of torque samples until all of the torque samples within the third group are measured. The precise number of torque values within the third group can be modified and can be dependent upon the sampling rate. For example, the third group of samples can include 15 torque samples, each measured at 10 ms intervals.

Some embodiments include collecting a fourth group of torque samples. In certain variants, after all of the torque samples in the third group have been analyzed according to block **226** and block **230a**, controller **20** can measure and carry out analysis on a fourth group of torque samples at block **230b**. As shown in FIG. **13**, in some embodiments, at block **230b**, controller **20** can compare one or more of the measured torque values in the fourth group to the breach threshold  $T_{Breach}$ . For example, at block **230b**, controller **20** can determine whether a current measured torque value within the fourth group is less than the breach threshold  $T_{Breach}$ . As another example, at block **230b**, controller **20** can determine whether two, consecutive torque values within the fourth group are less than the breach threshold  $T_{Breach}$ . As shown in block **230c**, if one or more recent torque measurements within the fourth group are less than the breach threshold  $T_{Breach}$ , as shown by block **230d** in FIG. **13**, controller **20** can move to block **240** and can reduce or stop rotation of drill bit **200**. As also shown in block **230c**, if one or more recent torque measurements within the fourth group are not less than the breach threshold  $T_{Breach}$ , as shown by block **230e** in FIG. **13**, surgical driver **100** can continue drilling of drill bit **200** and controller **20** can continue to collect and analyze torque values according to block **230b**.

In some cases, none of the torque samples in the third group registered that the drill bit **200** was drilling in/through the second cortical portion of bone **202**. In such cases, with reference to FIG. **12**, all of the torque values in the third group would have led to block **226b**. As a result, when controller **20** begins collecting torque values within the fourth group, there will not be a breach threshold  $T_{Breach}$  to compare such torque values with (e.g.,  $T_{Breach}=0$ ). In such

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cases, controller **20** can utilize the measured torque values from the fourth group to determine a rolling average and thus, breach threshold  $T_{Breach}$ , and thereafter compare subsequent torque measurements from the fourth group to such breach threshold  $T_{Breach}$ .

In some embodiments, controller **20** does not carry out block **230a**. In such embodiments, controller **20** can analyze whether torque values are decreasing, and immediately upon making such determination, can move to block **240** to reduce or stop rotation of drill bit **200**. For example, at block **230b**, controller **20** can compare a current (e.g., recent) torque value with one or more past torque values and determine, at block **230c**, whether the current (e.g., recent) torque value is less than such one or more past torque values. If the current (e.g., recent) torque value is less than such one or more past torque values, controller **20** can, as shown by block **230c**, move to block **240**. Alternatively, if a current (e.g., recent) torque value is not less than such one or more past torque values, surgical driver **100** can continue drilling of drill bit **200** and controller **20** can continue to collect and analyze torque values according to block **230b** (see block **230e**).

With reference to block **230c**, if controller **20** determines that torque values are decreasing or that torque values are dropping below a threshold (e.g.,  $T_{Breach}$ ), this can indicate that drill bit **200** has breached bone **202**. As discussed previously, such determination, and subsequent action taken according to block **240**, can advantageously inhibit or prevent drilling through tissue adjacent or proximate to bone **202**.

While the various steps and methods discussed above utilize the phrases “first group,” “second group,” “third group,” and “fourth group,” such phrases are not intended to be limiting. Such phrases are merely used to illustrate that one or more of the above-described blocks, steps, or processes measure and/or analyze one or more torque values to make various determinations that can advantageously help the controller **20** determine where drill bit **200** is with respect to the cross-section of bone **202**. For example, use of the phrase “first group of torque samples/values” with respect to block **222** is meant to convey that a certain amount of initial torque values are discarded prior to measuring/analyzing additional torque values. Use of the phrase “second group of torque samples/values” with respect to block **224** and FIG. **11** is meant to convey that a certain amount of torque values (measured after the “first group”) are measured/analyzed to determine whether the drill bit **200** is drilling in and/or has drilled through the first cortical portion of bone **202**. Use of the phrase “third group of torque samples/values” with respect to block **226** and FIG. **12** is meant to convey that a certain amount of torque values (measured after the “second group”) are measured/analyzed to determine whether the drill bit **200** is currently drilling in the second cortical portion of bone **202**. Additionally, use of the phrase “fourth group of torque samples/values” with respect to block **230** and FIG. **13** is meant to convey that a certain amount of torque values (measured after the “third group”) are measured/analyzed to determine where the drill bit **200** is with respect to the second cortical portion of bone and, more particularly, whether the drill bit **200** has drilled through the second cortical portion of bone **202**. While precise amount of torque values within the first, second, third, and/or fourth group can vary, the controller **20** can carry out the above-described blocks, steps, and/or processes in order to determine the precise location of the drill bit **200** with respect to the cross-section of any bone **202**.

The number of torque samples utilized and/or required in order to carry out the method/algorithm of FIGS. **9-13** can

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depend on factors including but not limited to the sampling rate, the thickness of bone, and the angle at which the drill bit **200** is with respect to an axis perpendicular to the bone surface. For example, if the angle of drill bit **200** with respect to an axis perpendicular to the bone surface is greater than 15 degrees, more than 25 torque samples may need to be taken in order to be able to carry out blocks **224** and/or **226**.

While FIG. **8** illustrates an example cross-section of bone **202** and points A-D represent points where drill bit **200** may pass through, any of the devices, methods, systems, and/or algorithm discussed above are applicable where drill bit **200** drills through alternative points, regions, or angles with respect to bone **202** as illustrated in FIG. **8**. For example, the method/algorithm described above with respect to FIGS. **9-13** is applicable where drill bit **200** drills through bone **202** at an angle that is non-perpendicular with respect to any point or surface along bone **202** and/or that is not aligned with a middle or center axis of bone **202**. Regardless of the precise angle of drill bit **200** with respect to a point or surface of bone **202**, the methods/algorithms described above with respect to FIGS. **9-12** can be utilized to determine whether a drill bit **200** is drilling through a second cortical portion of bone **202** in order to stop the motor **12** and inhibit or prevent damage to tissue proximate an exterior of the second cortical portion of the bone **202**.

#### Certain Terminology

Conditional language used herein, such as, “can,” “could,” “might,” “may,” “e.g.,” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

Conjunctive language, such as the phrase “at least one of X, Y, and Z,” unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be either X, Y, or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require at least one of X, at least one of Y, and at least one of Z to each be present.

The terms “comprising,” “including,” “having,” and the like are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations and so forth. Also, the term “or” is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term “or” means one, some, or all of the elements in the list. The term “and/or” means that “and” applies to some embodiments and “or” applies to some embodiments. Thus, A, B, and/or C is equivalent to A, B, and C written in one sentence and A, B, or C written in another sentence. The term “and/or” is used to avoid unnecessary redundancy.

The terms “approximately,” “about,” and “substantially” as used herein represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, in some embodiments, as the context may dictate, the terms “approximately,” “about,” and “substantially” may refer to an amount that is within less than or equal to 10% of the stated amount. The term “generally” as used herein represents a value, amount, or

characteristic that predominantly includes or tends toward a particular value, amount, or characteristic. As an example, in certain embodiments, as the context may dictate, the term “generally parallel” can refer to something that departs from exactly parallel by less than or equal to 20 degrees.

Terms relating to circular shapes as used herein, such as diameter or radius, should be understood not to require perfect circular structures, but rather should be applied to any suitable structure with a cross-sectional region that can be measured from side-to-side. Terms relating to shapes, such as “circular” or “cylindrical” or “semi-circular” or “semi-cylindrical” or any related or similar terms, are not required to conform strictly to the mathematical definitions of circles or cylinders or other structures, but can encompass structures that are reasonably close approximations. Likewise, shapes modified by the word “generally” (e.g., “generally cylindrical”) can include reasonably close approximations of the stated shape. As used herein, any discussion of the “drill bit,” such as the location of the drill bit relative to bone, can refer to the drill bit’s tip (e.g., the distal-most end of the drill bit).

Some embodiments have been described in connection with the accompanying drawings. The figures are drawn to scale, but such scale should not be interpreted as limiting, since dimensions and proportions other than what are shown are contemplated and are within the scope of this disclosure. Distances, angles, etc. are merely illustrative and do not necessarily bear an exact relationship to actual dimensions and layout of the devices illustrated. Components can be added, removed, and/or rearranged. Further, the disclosure herein of any particular feature, aspect, method, property, characteristic, quality, attribute, element, or the like in connection with various embodiments can be used in all other embodiments set forth herein. Additionally, it will be recognized that any methods described herein may be practiced using any device suitable for performing the recited steps.

#### Summary

Various surgical driver devices, systems, and methods have been disclosed in the context of aspects of certain embodiments, examples, and variations. The present disclosure extends beyond the specifically disclosed embodiments, examples, and variations to other alternative embodiments and/or uses of the invention, as well as obvious modifications and equivalents thereof. In addition, while a number of variations of the surgical driver have been shown and described in detail, other modifications, which are within the scope of this disclosure, will be readily apparent to those of skill in the art based upon this disclosure. Moreover, while certain examples have been discussed in the context of surgical drivers, the various inventions disclosed herein are not limited to use in surgical drivers. Indeed, the various inventions disclosed herein are contemplated for in use a variety of other types of devices and other environments.

Certain features have been described in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations, one or more features from a claimed combination can, in some cases, be excised from the combination, and the combination may be claimed as any subcombination or variation of any subcombination.

Any portion of any of the steps, processes, structures, and/or devices disclosed or illustrated in one embodiment,

flowchart, or example in this disclosure can be combined or used with (or instead of) any other portion of any of the steps, processes, structures, and/or devices disclosed or illustrated in a different embodiment, flowchart, or example.

The embodiments and examples described herein are not intended to be discrete and separate from each other. Combinations, variations, and other implementations of the disclosed features are within the scope of this disclosure.

Any of the steps and blocks can be adjusted or modified. Other or additional steps can be used. None of the steps or blocks described herein is essential or indispensable. Moreover, while operations may be depicted in the drawings or described in the specification in a particular order, such operations need not be performed in the particular order shown or in sequential order, and that all operations need not be performed, to achieve desirable results. Other operations that are not depicted or described can be incorporated in the example methods and processes. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the described operations. Further, the operations may be rearranged or reordered in other implementations. Also, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described components and systems can generally be integrated together in a single product or packaged into multiple products.

The various features and processes described above may be used independently of one another, or may be combined in various ways. All possible combinations and subcombinations are intended to fall within the scope of this disclosure. In addition, certain method, event, state, or process blocks may be omitted in some implementations. The methods and processes described herein are also not limited to any particular sequence, and the blocks or states relating thereto can be performed in other sequences that are appropriate. For example, described tasks or events may be performed in an order other than the order specifically disclosed. Multiple steps may be combined in a single block or state. The example tasks or events may be performed in serial, in parallel, or in some other manner. Tasks or events may be added to or removed from the disclosed example embodiments. The example systems and components described herein may be configured differently than described. For example, elements may be added to, removed from, or rearranged compared to the disclosed example embodiments.

In summary, various embodiments and examples of torque-limiting surgical driver systems and methods have been disclosed. Although the disclosure has been in the context of those embodiments and examples, this disclosure extends beyond the specifically disclosed embodiments to other alternative embodiments and/or other uses of the embodiments, as well as to certain modifications and equivalents thereof. Moreover, this disclosure expressly contemplates that various features and aspects of the disclosed embodiments can be combined with, or substituted for, one another. Accordingly, the scope of this disclosure should not be limited by the particular disclosed embodiments described above, but should be determined only by a fair reading of the claims that follow.

The following is claimed:

1. A torque-limiting surgical driver comprising:
  - a body comprising a handle that is configured to be grasped by a user;
  - a motor positioned in the body;

a drive head configured to be rotated by the motor and to receive a drill bit; and  
 a processor positioned in the body;  
 wherein, under the control of the processor, the torque-limiting surgical driver is configured to:  
 apply torque to the drill bit to drill into a bone;  
 monitor current or voltage supplied to the motor;  
 determine, from the current or voltage supplied to the motor, torque values applied to the drill bit as the drill bit drills through the bone;  
 determine that a torque-limiting condition is satisfied, wherein the determining that the torque-limiting condition is satisfied comprises:  
 determining that the drill bit has drilled in or through a first cortical layer of the bone; and  
 determining that the drill bit has drilled through a second cortical layer of the bone; and  
 in response to determining that the torque-limiting condition is satisfied, stopping the application of torque to the drill bit;  
 wherein the torque-limiting surgical driver is configured to:  
 determine whether the drill bit has drilled in or through the first cortical layer of the bone by comparing a difference between a first pair of torque values to a first threshold; and  
 if the difference between the first pair of torque values is not greater than or equal to the first threshold, compare a difference between a second pair of torque values with a second threshold, wherein the second threshold is greater than the first threshold.

2. The torque-limiting surgical driver of claim 1, wherein, if the difference between the second pair of torque values is not greater than or equal to the second threshold, the torque-limiting surgical driver is further configured to compare a third pair of torque values with the second threshold.

3. The torque-limiting surgical driver of claim 1, wherein the torque-limiting surgical driver is further configured to determine at least one of:  
 whether the drill bit has drilled through an entry point of the second cortical layer of the bone; and  
 whether the drill bit is drilling in the second cortical layer of the bone.

4. The torque-limiting surgical driver of claim 3, wherein the torque-limiting surgical driver is configured to determine whether the drill bit has drilled through the entry point of the second cortical layer of the bone by comparing a difference between a third pair of torque values to a third threshold, the third pair of torque values obtained after the first pair of torque values.

5. The torque-limiting surgical driver of claim 4, wherein the third threshold is equal to a percentage of an average of a subset of all determined torque values.

6. The torque-limiting surgical driver of claim 5, wherein the subset of all of the determined torque values is equal to all of the determined torque values that are greater than or equal to a fourth threshold, wherein the fourth threshold is indicative of drilling through a material other than air.

7. The torque-limiting surgical driver of claim 3, wherein the torque-limiting surgical driver is configured to determine whether the drill bit is drilling in the second cortical layer of the bone by comparing a difference between a current torque value and a maximum measured torque value to a third threshold.

8. The torque-limiting surgical driver of claim 3, wherein, in response to a determination that the drill bit has drilled

through the entry point of the second cortical layer of the bone or a determination that the drill bit is drilling in the second cortical layer of the bone, the torque-limiting surgical driver is further configured to determine an average torque value, the average torque value representative of the torque values measured when the drill bit is drilling in the second cortical layer of the bone.

9. The torque-limiting surgical driver of claim 8, wherein the torque-limiting surgical driver is further configured to determine a difference between a first torque value and the average torque value, the first torque value being a current torque value measured by the torque-limiting surgical driver.

10. The torque-limiting surgical driver of claim 9, wherein, the surgical driver is configured to limit an amount of torque applied to the drill bit in response to a determination that the first torque value is less than the average torque value.

11. The torque-limiting surgical driver of claim 9, wherein the torque-limiting surgical driver is further configured to:  
 determine a difference between a second torque value and the average torque value, the second torque value measured prior to the first torque value; and  
 limit the amount of torque applied to the drill bit in response to a determination that both of the first and second torque values are less than the average torque value.

12. A method of controlling a torque-limiting driver to limit the amount of torque applied to a drill bit after breaching a bone, the torque-limiting driver comprising a body with a handle, a motor positioned in the body, a drive head that is configured to receive a drill bit and to be rotated by the motor so as to enable the drill bit to drill into the bone, and a processor, wherein under the control of the processor the method comprises:

driving the drill bit into the bone, wherein the bone comprises a first cortical layer, a second cortical layer, and a cancellous layer in between the first and second cortical layers;

detecting torque values when the drill bit is drilling into the bone;

determining whether the drill bit has drilled in the first cortical layer of the bone, wherein said determining comprises:

comparing a difference between a first pair of torque values to a first threshold; and

if the difference between the first pair of torque values is not greater than or equal to the first threshold, comparing a difference between a second pair of torque values with a second threshold, wherein the second threshold is greater than the first threshold; determining whether the drill bit has drilled through and exited the second cortical layer of the bone; and

in response to determining that the drill bit has drilled through and exited the second cortical layer of the bone, stopping the driving of the drill bit.

13. The method of claim 12, further comprising determining at least one of:

whether the drill bit has drilled through an entry point of the second cortical layer of the bone; and

whether the drill bit is drilling in the second cortical layer of the bone.

14. The method of claim 13, wherein, in response to a determination that the drill bit has drilled through the entry point of the second cortical layer of the bone or a determination that the drill bit is drilling in the second cortical layer of the bone, the method further comprises determining an average torque value, the average torque value representa-

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tive of torque values measured when the drill bit is drilling in the second cortical layer of the bone.

15. The method of claim 14, further comprising determining a difference between a first torque value and the average torque value, the first torque value being a current torque value measured by the torque-limiting surgical driver. 5

16. The method of claim 15, further comprising limiting the amount of torque applied to the drill bit in response to a determination that the first torque value is less than the average torque value. 10

17. A torque-limiting surgical driver comprising:

a body comprising a handle that is configured to be grasped by a user;

a motor positioned in the body;

a drive head configured to be rotated by the motor and to receive a drill bit; and 15

a processor positioned in the body;

wherein, under the control of the processor, the torque-limiting surgical driver is configured to:

apply torque to the drill bit to drill into a bone;

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monitor current or voltage supplied to the motor; determine, from the current or voltage supplied to the motor, torque values applied to the drill bit as the drill bit drills through the bone;

determine that a torque-limiting condition is satisfied, wherein the determining that the torque-limiting condition is satisfied comprises:

determining that the drill bit has drilled in or through a first cortical layer of the bone by at least comparing a difference between a first pair of torque values to a first threshold and comparing a difference between a second pair of torque values to the first threshold; and

determining that the drill bit has drilled through a second cortical layer of the bone; and

in response to determining that the torque-limiting condition is satisfied, stopping the application of torque to the drill bit.

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